

II. EVOLUTIONARY THEORIES AND ASPECTS

3 Ecology. Life in the 'Unstable Biosphere'

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Abstract

The author analyzes the modern ecological situation, characterized by an imbalance in the circulation of matter and energy, reduction of the area of active functioning of the biosphere and biodiversity. Biosphere parameters are approaching acceptable limits of changes, the transition through which entails a loss of system stability and its destruction. Humankind, as thousands of years ago, obtains almost all food as a result of the use of soil energy in agriculture and animal husbandry. These circumstances are forcing many countries to expand plowing of land by reducing the area of forests, meadows, and pastures. Meanwhile, the share of arable soils on the planet and the productivity of biocenoses are declining. Replacing natural ecosystems with anthropogenic ones leads to the openness of the cycles of elements, primarily biophilic ones – carbon, nitrogen, phosphorus – and removal of elements from biological cycles, which in turn reduces the stability of the biosphere as a whole. Urbanization, which implies a loss of highly fertile agricultural land, deforestation, and a significant reduction in biological diversity has a serious impact on the global ecology. The author considers the problems of negative anthropogenic impact both within the framework of the global crisis and within the framework of local crisis conditions. The article analyzes the experience of implementing global and local measures aimed at minimization or elimination of the anthropogenic damage to the environment, as well as available theoretical and methodological scientific research from various countries aimed at solving the identified problems. The author outlines priorities in resolving those problems in the framework of the development of a science-based strategy for sustainable development as well as suggests measures to improve the environment and rehabilitate contaminated territories. The next few decades will be of decisive im-

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portance for the formation and implementation of a new global agenda aimed at ensuring the survival of the humankind.

Keywords: *biosphere, soil functions, deforestation, urbanization, anthropogenic impact.*

Current State

The natural environment around us in its natural state is a balanced system (akin to a living organism), in which individual groups of organisms, including humans, interact with each other and with the surrounding abiotic components without losing the quasi-static equilibrium. Such a state of the system is considered as stable. However, throughout the geological history of landscapes the phases of sustainable development of the biosphere were interrupted by natural disasters (volcanic eruptions, floods, falls of very large meteorites, etc.). Small biological and large geological cycles of elements, as well as energy cycles, secure the connections between functioning organisms and the abiotic environment.

In the course of its development, the humankind has been influencing natural systems, changing their capacity, as well as directions and speeds of natural processes, cycles of matter and energy flows. Quasi-equilibrium is disturbed by changing parameters, but not immediately. Each of the parameters is associated with other ones, and has the capacity (the ability of the environment to adsorb foreign substances, excess energy, etc. without changing its state) to compensate for the changes in neighboring parameters. This buffer reaction continues until the capacities of all parameters are exhausted. This property of the system is the theoretical basis for the concept of acceptable limits of change or growth limits (Rozanov 1984).

Acceptable limits of changes are the minimal and maximal critical values of the parameters of the state of the environment, within which it is stable and not destroyed. In its interaction with human beings, the environment can go through a number of critical points in its development:

1) Normal state of the environment is an ecologically balanced natural state corresponding to the totality of natural conditions and natural values of parameters.

2) Abnormal (disturbed) state is a state in which one or more parameters reach values that deviate from the background characteristics of a given area, or some properties of the environment are disrupted, for example, its carrying capacity. In an abnormal state, the environment does not yet lose its systemic integrity, but acquires the characteristics of an ecologically unbalanced system and may have a harmful effect on people or not satisfy their needs.

3) Critical state of the environment is characterized by the parameters of the state approaching acceptable limits to change, the transition through which entails a loss of stability of the system.

4) Destruction of the environment (crisis) is a state in which the environment becomes unsuitable for human habitation or use as a resource.

Current ecological situation is characterized by the following:

- planetary circulation of matter and energy is out of balance (the biomass of land has decreased, while the biomass of the ocean has increased; technogenic pollution of the biosphere, *etc.*);
- progressive expansion of the area of life was followed by a narrowing of the active functioning of the biosphere (mining, wars, construction);
- biodiversity reduction (by 8–10 % for vascular plants);
- weakening of the buffering capacity and the ability to self-clean;
- environmental disasters reaching continental and global levels as a result of natural-anthropogenic resonance;
- qualitative decrease in the viability of the environment;
- the ‘human-land’ system changing to ‘nomad-resource’ system; reduction of resources;
- urbanization has led to the emergence of entire regions that differ in their characteristics from the natural zones in which they are located. All cities in the world are similar to each other in environmental properties;
- most natural ecosystems of Europe, China, India, Central Asia, Turkey, and the Russian forest-steppe have completely disappeared (see Table 1).

Global crisis is to be distinguished from local crisis conditions. The latter in their totality do not always lead to global crisis due to the compensatory functions and great natural diversity. Meanwhile, natural climatic and landscape zoning is the most important theoretical basis for finding ways out of the current ecological crisis and the only basis for the sustainability of the planetary geobiosystem. That is why Vasily Dokuchaev, the discoverer of the law of geographical zoning and the founder of soil science, became the teacher of Vladimir Vernadsky, the founder of ecology (Chesnokov 2013). After all, the doctrine of the zones of nature is the antipode of the law for the struggle for existence, exaggerated by some of Darwin's followers, because animals, plants, microorganisms, and the landscape with its inherent features of soils, topography, climate, and geology coexist in every natural zone, in every biogeocenosis, interdependently and under conditions of self-regulation (Dokuchaev 1899).

Table 1. Areas with natural ecosystems disturbed to varying extent on the Earth's continents

Continents	Area, km ²	Non-disturbed territories, %	Partially disturbed territories, %	Disturbed territories, %
Europe	8,759,321	15.6	19.6	64.9
Asia	53,311,557	43.5	27.0	29.5
Africa	33,985,316	48.9	35.8	15.4
North America	26,179,907	56.3	18.8	24.9

Continuation of the Table

Continents	Area, km ²	Non-disturbed territories, %	Partially disturbed territories, %	Disturbed territories, %
South America	20,120,346	62.5	22.5	15.1
Australia	8,487,262	62.3	25.8	12.0
Antarctica	13,208,983	100.0	0	0
Land area, total	162,052,691	51.9	24.2	23.9
All land area without ice, rock, and bare surfaces	134,904,471	27.0	36.7	36.3

Source: Hannah *et al.* 1994.

The total size of the territory needed to ensure the vital activity of one person and to assimilate waste products varies from five to 12 hectares, of which one to two hectares are territories with destroyed landscapes (Kasimov and Klige 2006). Consequently, with a population of eight billion people, 60 to 120 million km² of developed land are required, along with 300 to 600 million km² of natural ecosystems for waste assimilation. The Earth's land surface is only 149 million km², and the area of the entire surface is 510 million km².

A significant part of artificial and natural ecosystems is degrading and faces additional risks due to climate change and the reduction of biological diversity. Between 1998 and 2013, about 20 % of the world's vegetated land showed a consistent downward trend in productivity, with 20 % of agricultural land, 16 % of forest land, 19 % of grassland and 27 % of rangeland showing a clear downward trend. These trends are especially worrisome given the increased demand for agricultural and livestock products, which require intensive land use. Highly productive plant formations are being replaced with unproductive and low-value ones. Broad-leaved forests and feather grass steppes have been completely destroyed. Anthropogenic badland makes up about 10 % of the land surface, the productivity of biocenoses is significantly reduced by 10–15 %, therefore, the carbon deposition capacity of the planet also decreases (Table 2).

Table 2. Carbon stored by the biome

Biome	Gigatons of C
Tropical and subtropical forests	547.8
Tropical and subtropical grasslands, savannas, shrubs	285.3
Deserts and dry bushes	178.0
Steppe, savannas and shrubs	183.7
Temperate forests	314.9
Boreal forests	384.2
Tundra	155.4

Source: Trumper *et al.* 2009.

Critical state of landscape that is approaching its critical threshold (Rozanov 1984; Golubev 1999; Randers 2012; Reymers 1994; *etc.*) is caused by well-known factors: 1) degradation of soil productivity as a result of irrational use; 2) reduction of natural vegetation; 3) pollution of landscapes by products of economic activities. The Human Ecological Footprint, as noted in one of the well-known reports to the Club of Rome, continues to increase following the increase in the Human Development Index and reaches maximum values in 'rich' countries (von Weizsäcker and Wijkman 2018).

In connection with rapid population growth, development of industry, construction of cities and transport routes, alienation of fertile soils from agriculture is increasing, and the rate of their anthropogenic degradation is growing. These circumstances are forcing many countries to expand the plowing of land by reducing the area of forests, meadows, and pastures.

Meanwhile, people still receive more than 98–99 % of food (by weight), including 87 % of protein (Dobrovolsky 1997), from the use of fertile soil in agriculture and animal husbandry. While during the first half of the 20th century the area of arable land per capita decreased in the world from 0.23 to 0.12 hectares, by 2005 it amounted to only 0.07 hectares (see Fig. 1; Modern global changes 2006). And this is already a critical value, which will be very difficult to compensate by further improvement of soil fertility. It is time to realize that fertile soil is the most important natural resource, no less important for human life than clean air and fresh water!

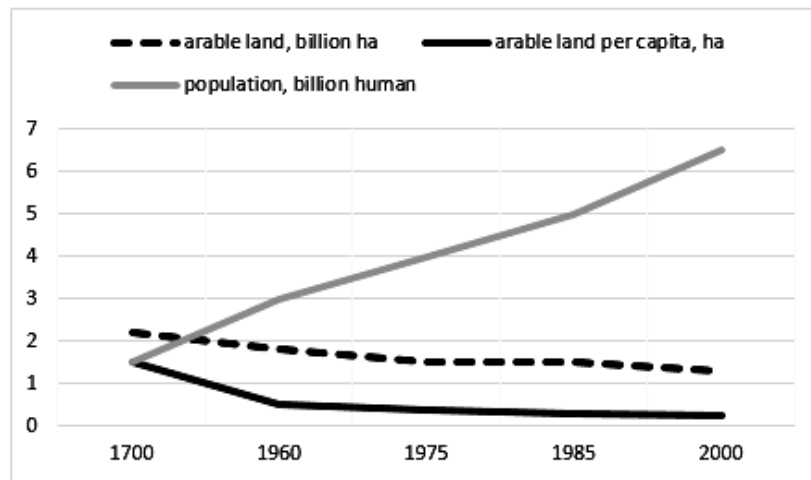


Fig. 1. Dynamics of arable land per capita

Source: Kasimov and Klige 2006; Ellis 2011.

Meanwhile, there are very few arable soils on Earth – they comprise 22 % of the earth's land area (see Table 1), that is about 3.2 billion hectares (Rozanov and Rozanov 1990). Of these, 1.5 billion hectares are currently under arable land, while 1.7 billion hectares remain unplowed – these are mostly soils that are insufficiently fertile and difficult to develop. In addition, according to a number of researchers, the total area of land that can be used for arable farming should not exceed 2.7 billion hectares. Then the reserve of arable land will be reduced to 1.2 billion hectares (Kovalev and Kovaleva 2020). This reserve is located mainly in the countries of the tropical belt under moist deciduous forests with red-colored acidic and leached ferrallitic soils, as well as in tropical and subtropical savannahs with alkaline soils. In Russia, after the plowing of virgin lands, there is no reserve of fertile, easily developed soils left (see Fig. 2).

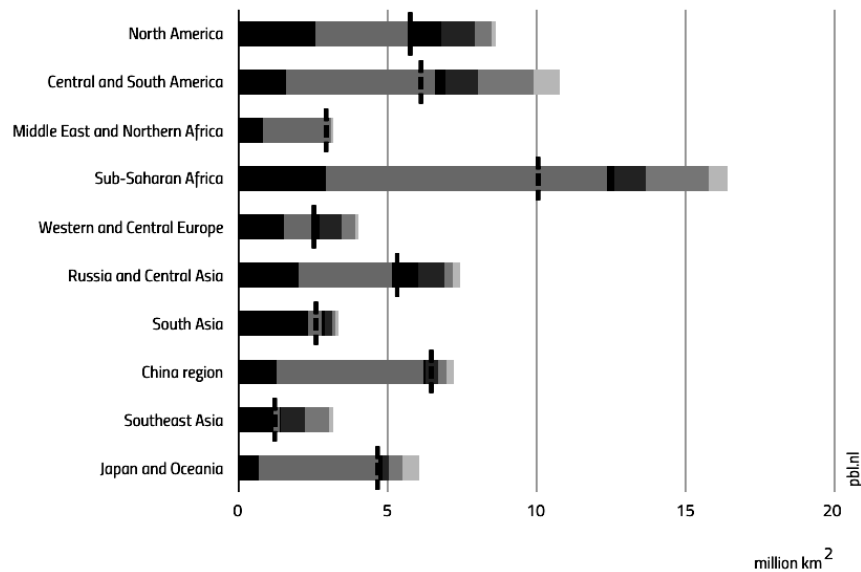


Fig. 2. Assessment of the land fund potential

Source: UN Convention to Combat Desertification 2017: 112.

The Netherlands Environmental Assessment Agency (PBL), in collaboration with Wageningen University, Utrecht University, and the Joint Research Center of the European Commission, has modeled possible scenarios for social development, taking into account the magnitude of global changes in land use and land conditions up to 2050. The 'Middle of the Road' scenario (SSP2) is

characterized by the continuation of current trends (as usual); the Green Sustainability Scenario (SSP1) represents a more equal and prosperous world committed to sustainable development; and the Fragmentation Scenario (FSP3) reflects a divided world with low economic growth, rapid population growth, and limited environmental concerns (Van Vuuren *et al.* 2014).

These scenarios are developed using the IMAGE.5 model by applying quantitative projections for population levels (Lutz *et al.* 2014), urbanization (Jiang *et al.* 2015), and economic development (Dellink *et al.* 2015), as well as by quantifying model parameters that reflect scenarios as described above. The outcomes of the scenarios cover the energy system, food production, land use, greenhouse gas emissions, climate change, biodiversity, and impacts on water and soil properties. Modeling of changes in soil properties, biological diversity and hydrological systems is supplemented with S-World models (Stoorvogel *et al.* 2017a, 2017b), GLOBIO model¹, and PCR GLOB WB model (Sutanudjaja *et al.* 2014; De Graaf 2014), respectively.

According to the Dutch PBL/IMAGE model, two out of three scenarios assume an increase in land use for agricultural purposes: it is expected that approximately 50 % (in SSP3) and 80 % (in SSP2) of this increase will occur in lands with low or average productivity. In contrast, under the WSP1 scenario, global agricultural land area will decrease as a result of a combination of low population growth, an increased focus on sustainable consumption and production (*e.g.*, reduced meat consumption and food waste), and more efficient crop and livestock systems. In Europe and Russia, which contain much of the world's most fertile land, even highly productive land will be subject to land-use change or will not be used. The largest expansion of agricultural land is in Sub-Saharan Africa due to high population growth (see Grinin and Korotayev 2023a; Korotayev, Shulgin *et al.* 2023) and an increase in demand for food and animal feed that cannot be met only by increasing the efficiency of agricultural production.

At the same time, about eight million hectares are annually withdrawn from agricultural use due to alienation for other economic needs, and about seven million as a result of various soil degradation processes (see Table 3). Thus, every year the humankind loses about 15 million hectares of productive land. Meanwhile, the process of soil degradation is happening at an exponentially increasing rate: over the past 50 years, it increased 30 times compared to the historical average during the Holocene (Kasimov and Krige 2006) (see Fig. 3).

¹ See URL: www.globio.info.

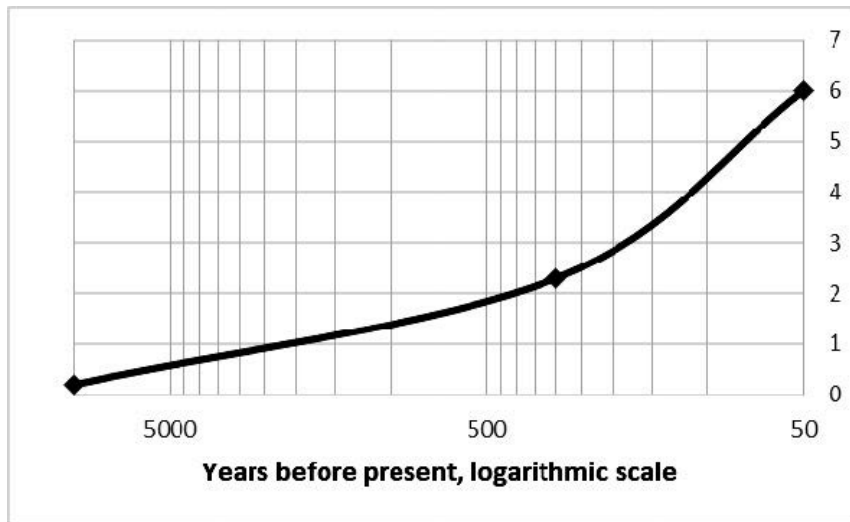


Fig. 3. The rate of productive land loss in the last 10,000 years

Source: Kasimov and Krige 2006.

Table 3. Degree of soil degradation

Degradation type	Area, mln ha	%
Washout and destruction by water erosion	1094	56
Dispersion and destruction by wind erosion	548	28
Chemical degradation (nutrient depletion, salinization, pollution, acidification)	239	12
Physical degradation (overconsolidation, waterlogging, subsidence)	83	4
TOTAL	1964	100
Degree of soil degradation		
Weak	749	38
Moderate	911	46
Strong	296	15
Very strong	9	1
TOTAL	1964	100

Source: Dobrovolsky 1997.

However, one of the underlying causes of ecological crisis is the underestimation of degradation processes at the level of the soil cover. It is not only

food security that is connected with the use of soil resources, but also the stability of the entire landscape of the Earth (see Table 4). To overcome this problem, the concept of ecological functions of soils was developed at Moscow State University (Dobrovolsky and Nikitin 1990).

Table 4. Global functions of soils (pedospheres)

Lithospheric	Hydrospheric	Atmospheric	General biospheric
Biochemical transformation of the upper layers of the lithosphere	Transformation of surface water into groundwater	Absorption and reflection of solar radiation	Habitat, accumulation of energy and biophilic substances
Source of matter for the formation of rocks and minerals	Participation in the formation of river runoff	Regulation of atmospheric moisture circulation	Connecting link in the biological and geological circulation of substances
Transfer of accumulated solar energy to the deep parts of the lithosphere	Factor of bio-productivity of water bodies due to the introduction of soil compounds	Source of solid matter and organisms entering the atmosphere	Factor of biological diversity and evolution of organisms
Protection of the lithosphere from excessive erosion and the condition for its normal development	Sorption barrier protecting water areas from pollution	Regulation of the composition and gas regime of the atmosphere	Factor of stability of the biosphere functioning

Source: Dobrovolsky 1997.

Anthropogenic ecosystems are aimed at achieving maximum productivity, while ‘unproductive’ natural ecosystems in terms of productivity are set up for maintaining the maximum stability of the biosphere, since, unlike agrocenoses, they are capable of self-regulation by maintaining the biological cycle of substances.² Replacing natural ecosystems with anthropogenic ones leads to disconnection of the cycles of elements, primarily biophilic ones, such as carbon, nitrogen, phosphorus, and to the removal of elements from the biological cycles, which in turn reduces the stability of the biosphere as a whole (see Fig. 4).

² On ecological situation and environmental change in the agrarian era see also Malkov, Kovaleva *et al.* 2023; for the industrial epoch see Akaev, Malkov, Davydova, Kovaleva *et al.* 2023.

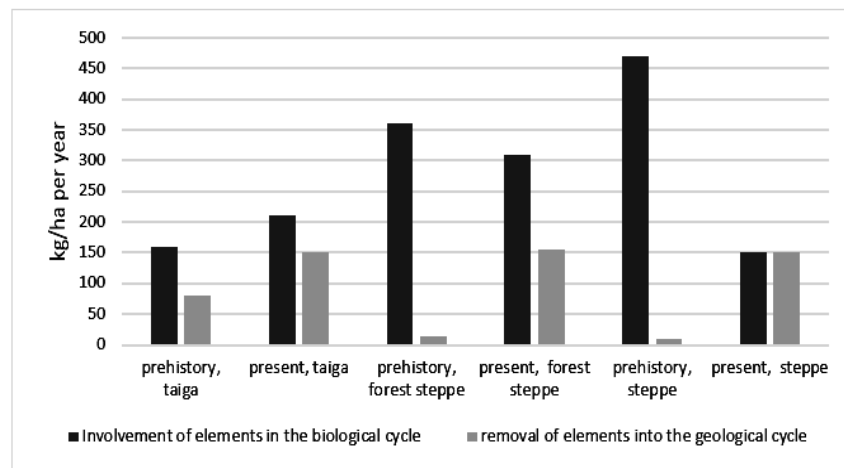


Fig. 4. Involvement of elements (total N, P, K, Ca, Mg, S) in the biological cycle and removal into the geological cycle, kg/ha per year

Source: Rozanov 1984.

The application of mineral and organic fertilizers can only partially improve the situation, since of the total amount of nitrogen introduced into the soil, agricultural plants use only 40–50 %. The rest is washed out in the form of nitrates polluting waters, or volatilizes into the atmosphere, polluting it with nitrogen oxides. A significant part of phosphate fertilizers is also leached into fresh water, causing eutrophication of waters (Bykovskaya *et al.* 1999). The introduction of large amounts of nitrogen fertilizers with a lack of phosphorus leads to poisoning of the produced products, the transformation of hard wheat varieties into soft ones and, generally, to the replacement of a large variety of plant and animal species with a small number of cultivated plant species and animals adapted to agrocenoses.

The total content of all chemical elements on the planet is almost unchanged, but their cycles have undergone transformations as a result of anthropogenic activity and the synthesis of new compounds and substances. The biological cycle is disturbed on half of the land surface (48 %): anthropogenic deserts comprise 5 %, badlands 3 %, residential areas 2 %, arable land, gardens, sown meadows 13 %, secondary low-productive forests 15 %, and pastures 10 % (FAO 2022). If we exclude glaciers, rocks, and deserts, then this is 60 % of the productive land surface. The geological cycle of elements is also subject to deformation due to 1) agricultural soil erosion and an increase in the amount of solid runoff; 2) the annual movement of thousands cubic meters of soil; 3) extraction of fossil fuels and their conversion into carbon dioxide, 4) extraction of

ores; 5) redistribution of salts as a result of irrigation and the construction of reservoirs; 6) use of fertilizers and pesticides; 7) pollution of the environment by industrial, municipal, and agricultural waste; 8) synthesis of substances that did not exist earlier in nature; 9) dispersion of geochemical accumulations in technogenesis.

However, pollution has a pronounced local character, although in some regions the pollution of water, soil, and air has reached critical parameters. At the same time, mining and agriculture (not industry) contribute the largest share to the composition of pollution.

The water parameter of the state of the environment has not changed significantly over time. The total amount of water on the Earth is stable and is maintained by the planetary water cycle in nature. The mass of water in the world's oceans (97 %) is stable, its salinity is constant. There are no significant changes in the composition of the water of the glaciers of Antarctica and Greenland (2 % of the total volume of surface waters). Minor fluctuations of ice sheets in the mountains and at high latitudes do not change the overall picture so far. However, the consumption of fresh water on land (one percent of the total volume of the hydrosphere), which is of vital importance for humans, is changing. The economic consumption of water has sharply increased (about 13 % of the river runoff, including 5.6 % irreversibly). Water pollution has risen sharply (16 % is polluted by sewage). The hydrology of the land has changed: small rivers disappear, large rivers are regulated by reservoirs, groundwater flow changes due to the drainage of swamps and deforestation. The drying up of floodplains and the development of soil erosion are intensified by active deforestation (GWP Technical Committee 2004).

The main feature of modern changes in the water regime of Russian rivers is a significant increase in water content during low periods, especially in the winter months. Another feature is the increase in the interannual runoff variability, especially the seasonal one. Against the general background of a trend towards an increase in river flow, both abnormally high-water and abnormally low-water years and seasons are possible. The features of modern changes in maximum water discharges are determined by the conditions of their formation. Thus, for a large area of the European part of Russia, where the maximum runoff is formed during spring flood, it has significantly decreased in recent decades. In the regions where maximum water flow is formed by rain floods (the Black Sea coast of the Caucasus, the Kuban and Amur basins), catastrophic floods occurred at the end of the last and beginning of this century, which had not been observed before. Estimates of possible changes in river runoff based on the analysis of reproduction of the components of water balance of watersheds carried out with the general circulation models of the atmosphere and ocean, show that in the coming decades the forecasted water regime will be

close to the conditions observed in the last 30–35 years in terms of its main parameters.

Forests cover almost a third of the land surface. The total forest area in the world is 4.06 billion hectares (ha), or 31 % of the total land area. This means that there is 0.52 hectares per capita, but forests are unevenly distributed across the world's regions. The largest part of the forests (45 %) is located in the tropical zone, followed by boreal (27 %), temperate (16 %) and subtropical (11 %) belts. More than a half (54 %) of the world's forests are found in just five countries: the Russian Federation (20 %), Brazil (12 %), Canada (9 %), the United States of America (8 %), and China (5 %) (FAO 2020).

During the existence of civilization, the area of forests has decreased by a half; meanwhile, the area of the evaporating surface of the forest canopy is close to the area of the world ocean, and the global production is 40 GtC/year (Gorshkov *et al.* 2000; Martin 2015) (see Table 5).

Table 5. Projected loss of forest area

Areas of deforestation	Projected reduction (million ha) by 2030
The Amazon River	23–48
Choco Darien	3
Cerrado	11
Gran Chaco Atlantic Forest	10
The Congo River basin	12
Coastal forests of East Africa	12
Borneo	22
Sumatra	5
New Guinea	7
Greater Mekong	15–30
Australia	6
Total	137–177

Source: Lanly 1982.

One hectare of forest absorbs about 10 tons of CO₂ per year. To absorb one billion tons of CO₂ annually emitted into the atmosphere for 50 years, we need one million km² of forest. In this case, excessive emissions that are not adsorbed by the existing flora and the world ocean could be reduced by 10 %.

Deforestation began in prehistoric times, it accelerated during European colonial expansion (Gadgil and Guha 1992), and continues to this day. In general, according to a review of satellite and ground-based data, the observed climate change has a stimulating effect on forest productivity. The increase in productivity of northern ecosystems is associated both directly with an increase in air temperature and indirectly with changes in soil temperature and the posi-

tion and dynamics of the roof of permafrost, due to its landscape-forming role. Changes in climatic characteristics lead to a change in the ranges of species, mainly of two types: 1) a shift in the ranges upwards in mountainous areas and 2) a shift in the ranges to the north. In the most temperate parts, forest area is now expanding from a historic low (Dudley *et al.* 2006), but this is more than offset by losses in the tropics (Pan *et al.* 2011). Many tropical forests that were partly deforested several decades ago have now practically disappeared (Lanly 1982).

Since 1990, the area of forests in the world has decreased by 178 million hectares, which is approximately equal to the territory of Libya. The rate of net loss of forest area between 1990 and 2020 has slowed noticeably as deforestation has declined in some countries and forest area has increased in others through afforestation and natural forest expansion. The rate of net loss of forest area decreased from 7.8 million hectares per year in 1990–2000 to 5.2 million hectares per year in 2000–2010 and 4.7 million hectares per year in 2010–2020. However, in the last decade, the net loss of forest area has occurred at a slower rate. The annual rate of deforestation in the last five years (2015–2020) is estimated at 10 million ha, up from 12 million ha in 2010–2015 (FAO 2020).

Despite the fact that the rate of overall deforestation is slowing down, the area of tropical forests in 2010–2015 decreased by 5.5 million ha every year (Keenan *et al.* 2015); other types of forests have been degraded (Sloan *et al.* 2015) or overgrazed, converted to shrubland, or plantations. Up to 70 % of the world's forests are at risk of further degradation (Haddad 2015). The net loss of forest area is expected to continue for several decades. Deforestation has a serious impact on the soil, especially if forests grow on peat, where deforestation threatens to emit large amounts of carbon, or in dry areas, where the disappearance of trees leads to rapid soil erosion.

Urbanization has a serious impact on global ecology. In many parts of the world, urban land is growing faster than the urban population. While the urban population is projected to reach 5 billion in 2030 and 6.3 billion in 2050, urban area is expected to triple from its 2000 baseline over the same period, an increase of 1.2 million km². Nearly 90 % of this growth is likely to occur in Asia and Africa, where urban populations are projected to rise to 56 % and 64 % respectively. According to current estimates, Africa's urban population will increase by more than 300 million between 2000 and 2030 (UN Population Division 2018).

Thus, by 2050, the world's urban population is expected to grow to approximately 6.3 billion people. This growth often leads to expansion of urban areas, some of them being built on top of fertile soils and agricultural land, resulting in the irreversible loss of arable land. Globally, about 2–3 % of the land surface area is now urbanized; by 2050, this indicator is forecast to increase to 4–5 % (UN Population Division 2018; Ellis *et al.* 2010; Ellis 2011; Hooke *et al.* 2012). At the same time, urban areas are expected to triple in size by 2030 in

some countries. Estimated losses from urbanization between 2000 and 2030 range from 1.6 to 3.3 million hectares of highly fertile agricultural land per year (Lambin 2011). In addition to the direct use ('withdrawal') of land, the 'ecological footprint' of urban settlements extends far beyond their borders. For example, a positive correlation has been established between tropical deforestation and urban population growth, as well as agricultural exports.

The increase in urban area is likely to lead to significant reductions in biodiversity, such as:

- Extensive urbanization in eastern Afromontana, the Guinean forests of West Africa and the Western Ghats, and the biodiversity hubs of Sri Lanka, will result in urban expansion of approximately 1900 %, 920 % and 900 % respectively by 2030 (more than 2,000 times), resulting in a serious reduction in biodiversity.
- In the already reduced and highly fragmented habitats, such as the Mediterranean and South American Atlantic forests, relatively small habitat loss can lead to a disproportionate increase in species extinction rates.
- The five centers of biodiversity with the largest areas expected to become urban are predominantly coastal areas or islands that are particularly important for endemic species.

Among other factors that cause severe damage to nature and which require special attention there are armed conflicts (see Appendix).

Prospects for Further Change in the Situation

The response to these challenges is quite simple: use less polluting energy sources (*e.g.*, biogas generators [Budzianowski 2016]), photovoltaic motors,³ more efficient energy saving solutions, and apply land use and management practices that prioritize the conservation of carbon in the soil.

Soil health can be improved by limiting soil damage and increasing soil organic matter, for example, through the use of improved crop varieties (including varieties of deep-rooted plants [Kell 2012] and cover crops [Poeplau *et al.* 2015]), crop rotation (Burney 2010) and, in some cases, no tillage (West and Post 2002). Soil erosion minimization interventions cover a wide spectrum from engineering interventions (such as terracing, lagoon construction (Pansak *et al.* 2008) and waterway improvement to vegetative interventions (such as agroforestry, cover crops [Agus and Widiyanto 2004]). Tillage farming can dramatically improve the physical properties of topsoil (Alvarez *et al.* 2009). Measures to reduce wind erosion include the use of drought-tolerant species, pasture rotation and windbreak planting, combined with no-tillage and stubble

³ See, *e.g.*, URL: <http://www.agrophotovoltaik.de/english/agrophotovoltaics/>.

conservation tillage practices (Fryrear *et al.* 1985). Halting soil degradation and the accumulation of soil organic matter also helps to mitigate climate change through soil carbon sequestration and, at the same time, helps to increase the resilience of agricultural systems (Amanullah 2016). An increased content of organic carbon in soil leads to an increase in crop yields, especially in areas with low and variable rainfall (Branca *et al.* 2013). Soil salinization is best prevented by using high quality irrigation water and ensuring proper drainage through the use of drainage pipes and/or drainage channels; periodic gypsumization of soils may also be required. Preventing soil compaction requires specific management, as recovery can take many decades. Long-term limited or anti-erosion tillage is considered as an effective approach in many regions of the world (Derpsch *et al.* 2010). While crucial to long-term soil health, these measures often do not provide immediate, tangible benefits for farmers and land users. For this reason, there are no direct stimuli for farmers to take conservation action, especially when they do not have land ownership, and stronger incentives are needed for that to happen (Hammad and Børresen 2006).

Sixty years ago, South Korea's GDP did not differ much from that of Kenya or Tanzania. Currently, an average wage in the country is approximately equal to the Australian one. Within a couple of generations, South Korea reached the ranks among the richest countries in the world. One of the reasons for this success was massive efforts to restore the environment. During World War II and the ensuing civil war, the country experienced devastating environmental degradation characterized by ecological crisis; most of the forests disappeared as a result of the conflict and fuelwood gathering. Since then, the Korean government has been implementing one of the most impressive reforestation programs in history, planting 2.8 million hectares of forests and increasing forest growth 12 times, as a result, much of the country is now covered with mature forests. Korea has established a system of protected areas covering an area of 16,000 km², which are extremely popular among the highly urbanized population of this country; in 2007, 38 million people visited national parks, 99 % of which were domestic tourists.

In some parts of the world, organic agriculture is no longer the prerogative of individual fields and is becoming the main or only model of production.

Example of India

In January 2016, Sikkim became the first state in India to go completely organic. It took ten years to convert 75,000 hectares of agricultural land in the state of Sikkim to the status of certified organic farms (Chamling 2010). The state now produces 800,000 tons of produce, nearly 65 % of India's total organic production of 1.24 million tons. Sikkim is a state which is a model for the

world because, while protecting ecosystem services, this model demonstrates that going organic does not harm productivity or development.

Example of Bhutan

In 2011, Bhutan set an ambitious goal of converting the country's entire agricultural system to organic production in the 2020s. If successful, Bhutan will become the world's first country with a completely organic food production. There are 700,000 people in this country, most of them farmers, so the only problem is to show that the benefits of such a system outweigh the costs, and that the use of natural fertilizers alone does not affect yields. Bhutan's organic strategy is to move from stage to stage, region to region, product to product, demonstrating that such innovations are necessary to find ways to naturally eradicate diseases and increase crop yields (Neuhoff *et al.* 2014).

All existing projection scenarios up to 2050 show that the strongest regional changes in land use are expected in Sub-Saharan Africa (see Grinin and Korotayev 2023a; Akaev *et al.* 2023); however, the best land is already being exploited and expansion will increasingly take place on less productive land, resulting in lower yields (by 20 %) (Rasmussen *et al.* 2016; Herrmann *et al.* 2014; Fensholt *et al.* 2012). In several regions, such as South Asia, there is either little or only marginal land left for agrarian expansion. As a result of ongoing changes in land use and the deterioration of soils, vegetation cover and biological diversity, extensive changes in the state of land resources are also forecasted in the future.

In terms of average relative abundance of species, the projected loss of biodiversity will continue at 4–12 % until 2050, and will also proceed for much of the second half of the 21st century. Changes in land cover and soil quality affect the likelihood of floods and droughts. These factors are even more intense in drylands, where more than average population growth is also expected.

To date, global soil organic carbon has been reduced by 176 Gt compared to its natural, undisturbed state. Losses of organic carbon in the humusosphere due to dehumification amounted to 313×10^{15} g over the last 10,000 years, including 90×10^{15} over the last 300 years and 38×10^{15} over the last 50 years (760 million tons per year). Since 1883, the humus content in the black soils of Russia has decreased from 10–12 % to 4–7 % (Kovalev and Kovaleva 2016). The annual intake of CO₂ from soils into the atmosphere due to 'breathing' is 60×10^{15} g of carbon, that is, the total loss of carbon by soils is two times greater than its entry into the atmosphere due to anthropogenic activities (Orlov *et al.* 2002). Therefore, the soil cover on which vegetation is restored is a carbon sink area, while the soils of the developed territories are the sources of carbon dioxide.

If current trends continue, anthropogenic emissions of carbon into the atmosphere from soil and vegetation on land for the period 2020–2050 will

amount to an additional 80 Gt, which is equivalent to about eight years at the current level of global carbon emissions from fossil fuels. Reducing these projected inland emissions would allow a larger global carbon budget of 170 to 320 Gt (*i.e.*, the amounts of CO₂ emissions that are still tolerable) to be left untouched without jeopardizing the goal of keeping global temperature rise below 2 °C (see Akaev and Davydova 2021). Despite the planet's significant potential for carbon storage in soils, this requires the development of agricultural systems that combine high yields with near-natural levels of soil organic carbon.

As early as the 1980s, Thomas Sankara, the revolutionary leader of Burkina Faso, proposed to re-green the savannas of the Sahel. In 2007, the initiative to create a 'Great Green Wall' in the Sahara and Sahel was adopted by the African Union. This initiative is a concerted regional strategy (African Union and Panafrican Agency of the Great Green Wall 2010) to create a mosaic of productive green landscapes in North Africa, the Sahel, and the Horn of Africa. The Great Green Wall, which will provide support for 232 million people, will run through arid and semi-arid zones north and south of the Sahara and will be a 15 km wide and 7,775 km long belt stretching from Dakar to Djibouti; the area of the main part of this belt will be 780 million hectares. About ten million hectares will need to be restored annually (UNCCD 2016). The goal of this wall is to reverse the effects of land degradation by 2025 and regional land transformation by 2050. Many changes have been already implemented (see, *e.g.*, African Union and Panafrican Agency of the Great Green Wall 2010; Ivie Ihejirika 2016):

- Ethiopia – 15 million hectares of degraded land restored, watersheds improved, tenure security improved; incentives are applied to encourage community involvement;
- Burkina Faso, Mali and Niger – about 120 communities are involved in the renewal of landscaping; more than two million seeds and seedlings of 50 native species were planted;
- Nigeria – 5 million hectares restored, including 319 km of windbreaks; 20,000 jobs created. In northern Nigeria, 5,000 farmers were trained in land restoration; more than 500 young people got jobs as forest guards;
- Senegal – 11.4 million trees planted; 1,500 km of fire barriers; promotion of natural revegetation applied on 10,000 hectares of land; in general, 24,600 hectares of degraded land have been restored;
- Sudan – 2,000 hectares of restored land.

Deserts occupy almost one-fifth of the entire territory of China, while most of the territory, especially the dry regions of western China (that are also among the poorest regions) is at risk of desertification. The livelihoods of 400

million people are threatened or affected by land degradation and expanding deserts. Rapid industrialization and urbanization have swallowed up agricultural land, exacerbating the already serious problem. Wood logging has made the land vulnerable to sand invasion. A prolonged drought in northwestern China has made the situation even more serious, intensifying dust storms and sandstorms. Since 1978, a 'Great Green Wall' of trees, shrubs, and grasses has been erected in the Kubuqi Desert to protect northern cities; it cost US\$ 6.3 million and slowed down the desertification from about 3,400 km² per year in the 1990s to 2,000 km² per year since 2001. By 2010, 12,452 km² of land affected by desertification had been restored, according to a government study, although desertification still increased in some areas (State Forestry Administration 2011).

However, the reality is much more complex than any model. The soil cover absorbs excess carbon dioxide, and the work of carbon landfills and carbon farms is based on this feature. At the same time, the initial amount of carbon in vegetation and humus is approximately the same, however, plants absorb 64–83 % (101–115 GtC) of all absorbed CO₂, while humus absorbs 6–7 % (7–10 Gt C), and litter absorbs 10 % (12–14 Gt C). However, the carbon reserves of humus grow the more intensively, the stronger the dependence of annual production on assimilable nitrogen.

All global models indicate that the secular trend of turning forest land into a fund of agricultural land will continue until at least 2050. Future needs for land use for agriculture will affect not only forests, but also savannahs and grasslands. As a consequence, the loss of natural habitats and associated impacts on biodiversity can be expected to worsen.

Thus, the humankind has found itself in the conditions of survival in the 'unstable biosphere'. The state of bifurcation can last for several centuries. Moderate optimism is based on the information that the reducing impact of modern civilization on the biological cycle has not reached the level of the Wurm maximum. This means that the elasticity of the global system is greater than we think.

Gradual change in the social structure of the population and mentality under the influence of a growing economy has already begun to lead to a decrease in population growth and limitation in resource consumption. There is a number of factors including widespread implementation of eco-policy measures in a number of developed countries, preservation of quite vast undeveloped territories as the basis for maintaining biodiversity in northern Eurasia and America, the ability of the biosphere to function geologically for a long time in conditions of homeostasis disturbances, and the inertia of many planetary systems and processes (*e.g.*, the world ocean) which allow forecasting the possibility of

long-term sustainable development, but not simultaneous in different states. To develop a science-based strategy for sustainable development, the following priorities should be recognized:

- ecological and economic optimization of natural-anthropogenic and anthropogenic systems by greening technologies and greening production⁴ (see Fig. 5), (this topic is also a subject of one of the reports to The Club of Rome [Wijkman and Skånberg 2017]),⁵

- a multifunctional approach to land resources; land use planning, taking into account land degradation neutrality (land degradation neutralization is a new approach to control land degradation, designed to encourage actions aimed at preventing or reducing degradation, as well as restoring degraded land in order to achieve the goal of zero balance loss of healthy, productive land at the national level);

- protection of natural systems and biodiversity through legal influence at administrative and international levels;⁶

- formation of a new approach to territorial planning, aimed at minimizing the consequences of uncontrolled urban sprawl and infrastructure development;

⁴ In 2014, India became the first country in the world to adopt a national agroforestry policy that encourages practices to grow trees, crops, and livestock at the same time on the same plot of land. Farmers have been growing trees on their plots for generations to help maintain soil conditions, as well as supply food, timber, and fuel. Intensive goat farming has led to the degradation of more than 1.5 million hectares of subtropical scrubland in the Eastern Cape of South Africa, resulting in the emergence of open desert-like landscapes in these areas with surface temperatures reaching 70 °C. The reduction or loss of almost all ecosystem services provided by these bushes have led to a decrease in farmers' incomes and a decline in the local economy. The question was how to restore the functionality of this ecosystem in order to extract the maximum environmental and economic benefits. In the early 1970s, a livestock farm owner living in the vicinity of Uitenhage took one small but important step to solve this problem. He built a barn at the foot of a degraded slope that flooded every time it rained. The farmer decided to try to restore the surface of the slope by turning it back into dense scrub to increase rainwater capture and prevent his barn from flooding. Together with other farmers, he set about restoring the shrub cover using cuttings from a local succulent tree, the elephant bush (*Portulacaria afra*); this resulted in improved soil quality and increased carbon stocks, and the area's animal feed productivity and income increased ten times. Based on the results of these advanced farmers and pastoralists, the South African government decided to invest in large-scale restoration of degraded bushland. The Subtropical Thicket Restoration Program was established, with approximately US\$ 8 million spent between 2004 and 2016. To date, over 10,000 hectares of nature reserves, private lands, and areas of the Addo Elephant National Park have been covered with elephant bush seedlings.

⁵ On optimum scenarios that could contribute to solving the climatic and environmental problems in technological, economic, social, demographic, and political dimensions see Grinin and Grinin 2023; Grinin, Grinin, and Malkov 2023a; Korotayev *et al.* 2023; Grinin, Grinin, and Malkov 2023b; Grinin and Korotayev 2023b; Grinin, Grinin, and Korotayev 2023; Grinin and Korotayev 2023a; Akaev, Malkov, Grinin *et al.* 2023; Korotayev, Shulgin *et al.* 2023.

⁶ These issues are covered in several reports to the Club of Rome (Perissi and Bardi 2021; Borgese 1986, 1998).

- prevention of total losses: creation of incentives for environmentally sound consumption of natural resources and extraction of natural raw materials;⁷
- formation of the resilience of communities and ecosystems to external influences, increasing the adaptive capacity of regions through a combination of environmental measures, sustainable management, and restoration of land resources (see Fig. 6);
- environmental education and enlightenment of the population in order to create a new worldview ('third consciousness' after the agrarian and industrial-technological waves).⁸

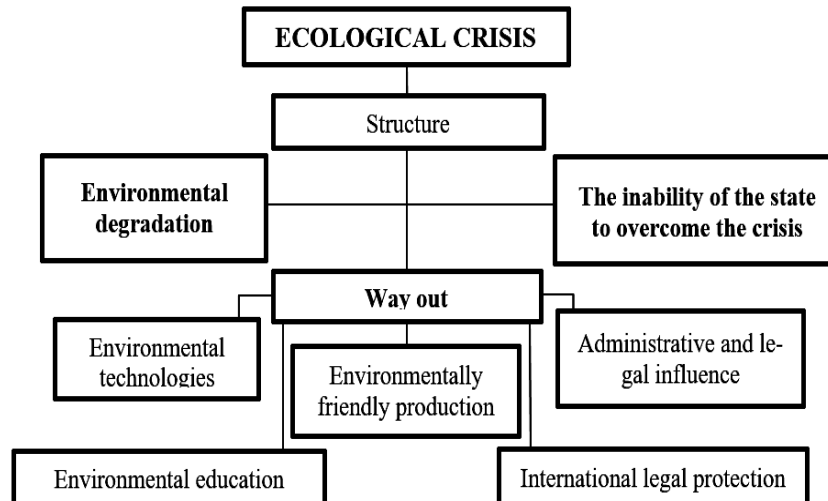


Fig. 5. Ways out of the global ecological crisis

⁷ The issues of uncontrolled spending of natural resources of the planet are covered also in a report to the Club of Rome by Ugo Bardi (2014).

⁸ In their report to the Club of Rome, Ilaria Perissi and Ugo Bardi (2021: 181) propose the use of simulation games as part of the education of the population, which make it possible to more easily explain what is not intuitive knowledge for people. By the latter, they mean the issues of saving natural resources, since intuitively people strive to achieve prosperity through economic growth, increasing profits, and the negative consequences of this are not intuitively felt, this requires additional reflection, to which the majority of the world's population is not too inclined. Therefore, the authors propose to use more familiar and easy-to-learn formats of education and enlightenment on the issues of saving the biosphere from anthropogenic impact. An example of such a game is described in detail in Section 'Moby Dick: The Game of Fishing' of the report. There are also several other reports to the Club of Rome, devoted to the issues of education in terms of educational program on global problems and processes (Andersen 2020; Bozesan 2020; Berg 2019; Korten 2015; Giarini and Malitza 2003; Vester 2002; Peter 1998; Botkin *et al.* 1979).

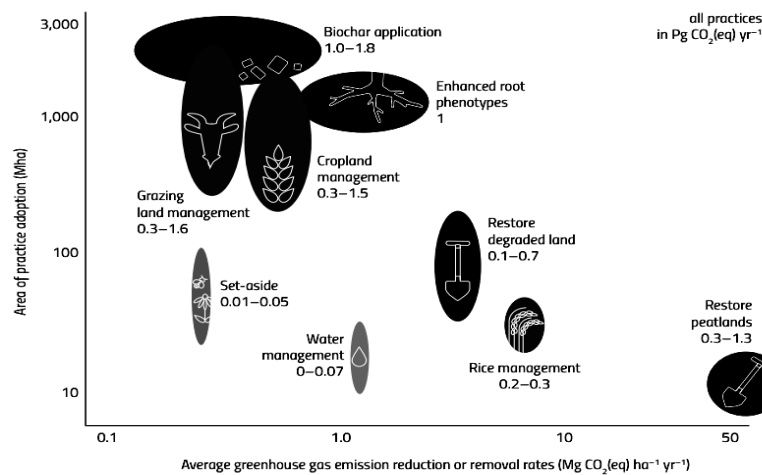


Fig. 6. Reducing greenhouse gas emissions from agriculture (UNCCD 2017). Global potential for agricultural-based GHG mitigation practices, where 1Pg (Pentagram) equals 1 billion metric tons and Mg (Megagram) equals 1 metric ton

Source: Paustian *et al.* 2016.

It is obvious that the next few decades will be of decisive importance for the formation and implementation of a new global agenda aimed at ensuring the survival of the humankind.

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Appendix**Armed Conflicts and Environment**

Military actions cause large-scale, long-term and severe damage to forests, fertile land, and pastures. 'Cleansing of nature' through the destruction of vegetation and soil becomes a war against future generations of inhabitants. In the period of armed conflicts, special aspect of environmental security becomes relevant – protection of the environment from destruction. Military actions that destroy natural environment are called ecocide or deterioration. One thing is beyond doubt – almost all military operations are always accompanied by changes and destruction of natural environment. Let us take as an example only two aspects of military conflicts' influence on ecology. First, it is military engineering (earth) works on the construction of defensive and other military facilities (trenches, roadblocks, dugouts, *etc.*), placement of military equipment that lead to change in relief, formation of artificial excavations and dumps, movement of soil, surface and deep influence on the soil, underlying rocks and vegetation, destruction of vegetation, wind and water erosion, change in the water-air regime of soils, disturbance of natural soil process, growth of buried soils.

Second, it is the direct effect associated with changes in the surface due to explosions, and the indirect effect caused by shock waves and disturbance of the stability of the soil cover. On the plains, the indirect effect is relatively small, but in the mountains, it is significant and depends on the steepness of the slope, the mass of soils moving due to the activation of erosion processes. Landslides create huge masses of friable gravelly deposits at the foot of the slopes.

It is already clear that the destruction of nature by military action will have profound long-term consequences. In any environmental impact, the greatest danger is not immediately occurring effects. Much more worrying is the prospect of those significant slowly accumulating changes that can occur due to poorly understood chemical reactions.

The following measures will be required to improve the environment and rehabilitate contaminated territories affected by military actions:

- identification of sources of pollution, localization and elimination of oil pollution of the territory at the locations of military equipment, wells and oil refineries;
- examination and assessment of the degree of pollution of surface and groundwater used as drinking water by cities and towns;
- undertaking initiatives to mitigate the risk of surface water contamination;
- work on localization and extraction of oil products from long-term man-made deposits;
- inspection of radioactive waste disposal sites;
- restoration of the state service for monitoring the state of the environment.