GENERAL ECOLOGY

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UDC 574

V.I. VERNADSKY AND MODERN ECOLOGICAL PROBLEMS

SUMMARY. General concept of V.I. Vernadsky's noosphere presupposes harmonious co-evolution of humanity and nature. The reality is that human activity has led to the emergence of anthropogenically induced processes and evolutionary transformations in the biosphere, which became dramatically evident in the middle of the last century. This article provides a brief analysis of the major changes of biogeochemical stages on the global scale. There are the examples of the cascade development of some negative phenomena under the influence of: increase of carbon dioxide content, acidifying agents content, enrichment of natural environments with metals, contamination with resistant organic matters, biogenic elements. There are proofs that the organic world reacts to anthropogenic transformation with active microevolution processes. Methodology for determining the critical loads is considered, as scientifically-based strategy for limitation of anthropogenic impacts on nature and for environmental harmonization. A characteristic of the theoretical foundations for the permissible flows of certain pollutants is given. It is shown that the development of environment-oriented non- and low-waste technologies with the consideration of science-based critical loads on the biosphere and its ecosystems, the rehabilitation of disturbed lands and water areas is a key direction in maintaining life-supporting environment of our planet.

KEY WORDS. Biosphere, pollution, biogeochemical cycles, environmental impacts, human-induced evolution, critical load.

INTRODUCTION

The general concept of V.I. Vernadsky's noosphere presupposes harmonious co-evolution of humanity and nature. In reality human activity has led to the emergence of anthropogenically-induced processes in the biosphere, which became dramatically evident in the middle of the last century. This article provides a brief analysis of the major changes of biogeochemical stages on the global scale. There are the examples of the cascade development of some negative phenomena under the influence of: increase of carbon dioxide content, acidifying agents content, enrichment of natural environments with metals, contamination with resistant organic matters, biogenic elements. There are proofs that organic world reacts to anthropogenic transformation with active microevolution processes. Methodology for determining the critical loads is considered as scientifically-based strategy for limitation of anthropogenic impacts on nature and for environmental harmonization. Theoretical foundations for the permissible flows of certain pollutants are given. It is shown that the development of environment-oriented non- and low-waste technologies with the consideration of science-based critical loads on the biosphere and its ecosystems, the rehabilitation of disturbed lands and water areas is a key direction in maintaining life-supporting environment of the planet.

Anthropogenic impacts and changes in biochemical cycles

Changes in biosphere and ecosystems (structural units of the biosphere) occur under the influence of many conjugated anthropogenic factors, the superposition of which may enhance or neutralize their impact; besides the developing cascade reaction of successive transformations in the biosphere affects all Earth Shells and their inhabitants. Change of biogeochemical cycles is generated by the following key factors:

— extraction and burning of hydrocarbon, leading to the increase of greenhouse gases and carbon cycle disruption;

— extraction of mineral resources, ore dressing and smelting of metals, leading to their dispersal in the environment and emission of acid gases;

— synthesis of thousands of new chemical compounds with toxic properties, which are involved in the biogeochemical cycling;

— artificial soil application with nutrients in the form of fertilizers, leading to disruption of phosphorus and nitrogen cycles;

— disfigurement of natural landscapes: desertification due to improper land use; expanding the area of man-made wasteland around the large-scale industries; wind and water erosion of soils; waterlogging and salinization; cession of land for construction and other purposes; activation of landslides, karst, mudslides, flooding, permafrost and other adverse processes.

The above list of factors determining biogeochemical cycles disruption is far from complete, but suffice to formulate the main question – how the anthropogenic changes in the environment that actively manifested in the last hundred years, will affect the evolution of the organic world and the biosphere as a whole.

Climate Warming and Disruption of the Carbon Cycle. In the previous years much attention of the scientific thought is given to the study of global warming, as the consequence of increasing greenhouse gases in the atmosphere. Recent studies reinforce the hypothesis that in the modern period human activity has a great impact on the global warming. Since 1980 the average temperature on the planet has risen by 0.5 degrees Celsius and the Earth is heating up by about 0.16 degrees per decade. Among the most proven environmental consequences of global warming there are instability of the weather, changing rainfall and hydrological cycles violation – an increase of periods of droughts and desertification in warm climates, augmentation of rainfalls in damp zones. Increase in carbon content along with temperature is leading to the raise of forests, oceans, rivers and lakes bio-productivity [2].

Past events on the Earth were marked with warm epochs giving way to climate cooling, then followed by the re-warming. 60-70 million years ago the concentration of CO_2 was twice as high as now [3]. In this context, modern geological processes should seem insignificant, but they trigger a cascade of complex irreversible processes.

For example, phenomenon of acidification of the ocean surface layers is one of the side effects of global warming. Before the industrialization, the value of pH in ocean water was 8.16, now it is 8.05. As stated in the work [2], during the XXI century the acidity (pH) of ocean surface waters may decrease by 0,14-0,4 units, i.e. go down to the values 7,96-7,7. According to J. Bijma et al. [4] ocean acidification is now happening faster than ever in the history of the Earth, and if you consider the levels of partial pressure of carbon dioxide, which we have already achieved, then you need to go back 35 million years to find any equivalents. There is no doubt that lowering of the pH values of ocean surface waters will affect ecosystems and it is able to cause a change in the food chain.

Local increase of organic matter content in water courses, which cropped up in the north of Europe and in America is one of the most significant indirect effects of climate warming in the northern latitudes. According to our research, the carbon content in the Russian Arctic waterways has increased by 11% over the last twenty years. Judging by this data, the approximate calculation of the carbon stock from the territory of Russia into the Arctic Sea reveals an increase of 350 tons per year during the last 20 years. There were several hypotheses made to explain the increase in organic substance in watercourses. Most scientists attribute this phenomenon to global warming, other – to disruptions of biogeochemical cycles in the "dam-foundation" system. This disruption happens under the influence of a long period of acid rains and renovaton of water in the last 20 years [5]. However, the increase in organic carbon release into the oceans can cause a step-by-step succession of ecosystem reorganization in the coastal areas.

Biogenic Pollution. Phosphorus and Nitrogen Cycle. Natural phosphorus gets into the environment being the result of rock decay; about one million tons per year is added to the natural cycle of this element. About 20 million tons of phosphorus is used annually in the fields or in the form of mineral fertilizers, only 60% of it is absorbed by plants, the rest is washed into rivers and the Ocean, scattered with dust particles, leading to the productivity increase of land ecosystems and eutrophication of aquatic ecosystems [6].

Global increase of the nitrogen content happens because of the contamination of land and seas by fertilizers, household sewage, fuel combustion and polluter atmosphere deposition. Humanity annually uses about 150 million tons of nitrogen in total. Historically emissions of NO_X began to increase in the late 1800s, and especially in the early 1900s. From the use of fertilizers NH_3 emission in the environment began to grow rapidly in the last three decades, especially in Asian countries, and exceeded NO_X emissions in the late 1980s. In the estimation of Galloway et al. [7] production of nitrogen oxides from combustion is determined by 20 million tons of N per year, which is twice as high as the natural emission of 9 million tons per year.

Another 80 million tons of N per year are added to the environment due to mineral fertilizers. Additionally, about 50 million tons of N per year is released into the atmosphere as NH_3, which is 2.5 times more than the emission of NO_X from the combustion of coal. NO_X emissions prevail in countries with high gross domestic product, and the emission of NH_3 dominates in the countries focused on food production [7]. Despite the fact that humanity has learned to control the process of aquatic ecosystems eutrophication, the dual impact of phosphorus and nitrogen hydrosphere enrichment in a number of lakes and coastal areas is catastrophic. It leads to the proliferation of blue-green algae that emit natural toxins of neuro-paralytic effect and cause suffocation of aquatic organisms, leading to the chain reaction of irreversible changes in ecosystems.

Analyzing the past eras, we can find the evidence of similar ecological disasters. J.W. Castle, J.H. Rodgers [8] put forward a hypothesis that the flux of biogenic elements into the environment increased dramatically because of the huge emissions of dust after explosions and fires, thick mats of blue-green algae formed in lakes and seas that could poison everything around with the produced toxins. Scientists note that their findings apply not only to the history of life on the Earth, but also to its future.

Nitrogen in the biosphere has a more complex cycle, it induces various ecological processes: eutrophicating, acidifying and ecotoxic, in which the nitrogen enrichment of the biosphere plays the key functions [9]. The least well-known effect of hydrosphere nitrogen pollution is its property to form nitrosamines, very toxic organic nitrogen compounds, both in the aquatic environment, and endogenously in the organisms themselves. Nitrosamines can cause tumors in practically all organs of animals and humans; they have mutagenic and transplacental effects. In some local areas of the Black Sea high concentrations of nitrosamine are found in water and in the muscles of commercial fish as the consequence of enrichment of aquatic environment with nitrogen [9]. Unfortunately, it is very difficult to reduce the flow of anthropogenic nitrogen and phosphorus into the biosphere, because namely mineral fertilizers are the necessary condition for further providing the mankind with food.

Acidic deposition. During the last century global pollution made with acid-forming substances (oxides of sulfur and nitrogen), coming mainly from the combustion of oil, coal and smelting ores, led to the formation of acid rains, which caused the acidification of soils and waters. In Europe and North America the level of anthropogenic sulfur emissions was rapidly growing in the beginning of the twentieth century and reached maximum values to the middle of the century. In the past 20 years, despite the significant reduction in SO2 emissions in Europe and North America, precipitation of sulfates on the watershed is at least 10 times higher than the level of the preindustrial period [7]. As noted, the nitrogen emissions are increasing.

Despite the recent trend of the developed countries to reduce emissions, the growing production of the developing countries, especially of China, will increase the emission of acid gases in the global scale. A number of scientific publications show that acidic deposition happens not only locally, it changes the transportation flow of elements in the Earth Shells. Primarily strong acids increase chemical weathering of the main cations and some metals, alter biogeochemical cycles of elements in the lithosphere and in freshwater hydrosphere. Under the influence of acidifying substances deposition and their dry absorption by underlying surface the following factors occur: saturation of soils in watersheds decreases on exchangeable bases, as well as their content in surface and ground waters; water alkalinity is reduced as a result of hydrocarbons displacement with stronger technological acids, metals leach from rocks that form watersheds (Al, Cd, Zn, Mn, etc.). There is a decrease in biodiversity at all levels of acidified ecosystems happening due to the elimination of species that are the most sensitive to low pH. It is not so much the impact of low pH that causes degradation of fish populations in acidified water systems, as the influence of Al^{3+} and other metals that leach and migrate into the water systems in the most toxic ionic forms [10].

Enrichment with Heavy Metals. Many elements in the environment take on toxic properties after having been produced from the earth interior and enriched in the technological cycles. "Technophility" of many metals, i.e. the ratio between their annual mining and their percentage abundance in the crust, reaches high values: Pb — 210^9, Cu — $1,110^9$, Cd — 110^8, Zn — 410^7, Sr — 710^6, Ni — 710^6 [11]. Metals enter the environment as part of flows and emissions of various industries, as part of refuse dumps, diffuse sources, they are leached by acidic disposition etc. Analysis of the spatial distribution of elements on the territory of European Russia and Western Siberia confirmed that technogenic dispersion of elements on a global (regional) basis, as well as leaching with acid depositions entail the tendency to water concentrating with dangerous elements such as Hg, Pb, Cd, Al, Cr, As and Se. The extensive development of the electronic industry results in growth of elements such as Pt, Rh, Pd, Ga, and Ir with their unexplored ecotoxic properties [12].

The main property of metals is that after release into the environment they do not fail and thus in high concentrations are harmful to living organisms. It is known that mercury has neurological effects, cadmium and lead have cancerogenic and gonadotoxic properties; the excess of trace elements in the body leads to endemic diseases: strontium — to bone tissue pathologies, molybdenum — to gout, copper — to anemia, etc.

Synthesized Organic Xenobiotics. Toxic organic compounds are highly hazardous to the environment. They include new synthesized compounds and substances activated from natural sources, obtained during the combustion of hydrocarbons, or as by-products of various industries. Their content in the environment is growing rapidly. According to EPA research [13], the total number of synthesized chemicals used is more than 5 million items and more than 2 thousand new substances created per year.

Drawn into global transportation flows of substances, new organic synthesized compounds can long cycle in the biosphere, poisoning air, water and foodstuff. Superecotoxicants include persistent organic pollutants (POPs): organochlorine pesticides, dioxins, furans and other. They spread in the environment far beyond their original location. Residues of organochlorine pesticides are found in the fat of seals and in the breast milk of the Far North women from Greenland, Canada and Siberia. In the early 1990s, the content of POPs in the environment was apperceived to be steadily growing. In many countries special measures were taken to limit the spread of these substances into the environment, but the contamination of natural environments with supertoxicants continued to increase. If in the European countries and America their use was prohibited long time ago, then many developing countries still continue to use them. It is estimated [13] that in the long view the accumulation of these substances in the biosphere will continue by means of the developing countries.

Radiological load on the biosphere. To the middle of 70s global contamination was more than $5{,}5\text{-}10^{11}$ Bq (becquerels) as a result of nuclear explosions, and more than $1{,}9\text{-}10^{11}$ Bq because of radioactive waste input to the World Ocean. Areas of the temperate latitudes, especially in the Northern Hemisphere, are the most polluted. The most typical anthropogenic radiative effects on the environment are: pollution of atmosphere and territories with products of nuclear explosions when testing nuclear weapons in the 60-ies, poisoning the air basin with emissions of radioactive dust, contamination of land slag containing radioactive substances, emissions from fossil fuels in power plants, areas pollution after accidents at nuclear power plants and factories [14]. There is a big variety of scientific literature on various aspects of the negative impact of radionuclides on living organisms.

Summarizing, perhaps, the incomplete analysis of the factors of biogeochemical cycles of substances changing in the biosphere, we should remark, that V.I. Vernadsky predicted the impact of human activities on the biosphere to be a geological factor in evolution. He considered it enormous and taking shorter time periods comparing to the period of geological processes and the formation of the modern aspect of the biosphere.

Anthropogenic evolution

The contemporary period of anthropogenic changes on the planet can be compared to the crucial moments in the biosphere development. Its modifications become the factors of the further evolution of organic world, the most important component of the biosphere. V.I. Vernadsky was one of the first to establish the idea that the surface shell of the Earth evolves as an integral process of interaction between living organisms and inert matter. Environmental pollution in modern conditions is included in a number of major abiotic factors affecting plant and animal populations. In recent biology there are more examples showing that living organisms react to anthropogenic pollution with active adaptive processes [15, 16]. Over the course of the biosphere evolution natural disasters and extreme conditions took place. Living organisms were faced with overcoming those or other adverse effects, and in the process of evolution they have undoubtedly developed mechanisms for the protection and conservation of their vital capacity.

Environmental pollution undeniably creates extreme conditions for life. S.S. Schwartz [17] noted that animals are subjected to additional energy expenditure in any extreme conditions, i.e., at any changes in lifestyle factors that are associated with living in more severe conditions, or require to lead a more active lifestyle. Such common factors are expressed so clearly that they are brought to the level of "laws". Undoubtedly, pollution of the environment is related to extreme conditions. Different mechanisms control the ability to survive in polluted environment: avoidance, reduction in sensitivity and cell permeability to poisons, increased activity of functional oxidases, metallothionein induction, sequestration, enhanced excretion of ecotoxicants [1].

There is a big amount of numerous scientific facts about genetic changes in animal populations under the influence of toxic pollution that confirm the existence of human microevolution [15, 16, 18]. These facts show that in terms of pollution, on the one hand, there will be the loss of genetic diversity and the accumulation of recessive mutations and on the other, high concentrations of pollutants will lead to the selection of the most resistant genotypes, which will inevitably affect the genetic pool. Reduction of genetic diversity may increase resistance to a certain type of toxicant and reduce adaptive capacity of animal populations to other stress conditions in general. Selection of genotypes resistant to the action of pollutants may indicate that the population is under pressure of pollution for a long period.

However, there are questions that are not yet fully clarified and that are extremely important in theoretical ecology. The first one is: How the influence of toxic substances will affect the genetic structure of the population? And the second: To what remote effects will the violations of the molecular-cellular and organismic level lead to?

The concept of critical loads limited by anthropogenic impact

Regarding the process of human interaction with nature it is necessary to consider the progressing evolution of the biosphere, but it is difficult to follow the interdependent and long-term consequences of our interference in natural processes. According to V.I. Vernadsky, the main problem in studying evolution of the biosphere was to establish a connection of "evolution of the species with the mechanism of the biosphere and the course of biogeochemical processes" [1].

However, the extensive knowledge on the transformations of organic world and the Earth spheres negatively influenced by humans, demand to restrict our negative influence and to conserve favorable living conditions. Obviously, the development of civilization can not be stopped, so the biosphere will continue its evolution, but the target and the speed of this process will be largely determined by our activity. The above examples show that pollution leads to cascade changes in the global biogeochemical cycles and consequently to the irreversible evolution of the biosphere. Marking a qualitative change in the history of the biosphere, V.I. Vernadsky wrote: "We live in Psychozoic era, an exceptional period in the history of the planet. The period when its new state, the noosphere, has been created, and when a geological role of humans starts to predominate in the biosphere and the perspectives for its future development appear" [1]. This results in a logical question: Is V.I. Vernadsky 's notion of the noosphere as of the harmonious co-evolution of humans and nature, a utopia or an achievable goal from the modern science point of view?

The concept of regulation based on self-purification capacity of natural environments was stated in the 1970-1980's, when the humanity became aware of all the disastrous consequences of the industrial activity on the planet. A number of Western scholars severely criticized it as pollution-legalizing. The principle of "zero discharge" was brought forward, which, in our opinion, is utopian in its turn. Undoubtedly, pollution prevention, instead of dealing with the consequences, should be one of the guiding principles. The question is how to define the border, "the red line" of changes acceptable from our point of view?

Up to the present, Russia and most countries have been taking decisions to limit anthropogenic load, comparing measured concentrations of specific pollutants and their correlation with maximum permissible concentration (MPC). It is acknowledged that the system of pollutants abatement, based on MPC of harmful substances, is not perfect and does not adequately assess the condition of natural environments.

The concept of ***critical loads*** appeared during the last decades as evidence-based strategy to prevent degradation of natural systems and to manage the state of natural objects [19]. The term "critical loads" means the maximum permissible release of one or more pollutants into the ecosystem, causing no adverse changes in the most sensitive of its links. The theory is based on the solution of complex problems in geo and biosciences, such as regularities of input and behavior of human-introduced elements, interaction with natural factors, insert into the natural cycle of elements, as well as mechanisms of antropogenic variability in biological systems, sustainability and adaptation limits, remote consequences of ecotoxicants influence on living organisms. Without studying these problems it is impossible to determine how long natural environment is able to assimilate the flow of pollution without negative consequences for living systems, i.e. reasonable limits of the impact on the environment.

As shown above, the modern period is characterized by a large variety of anthropogenically-induced phenomena in nature when living organisms are affected by a result of all direct and indirect effects of complex pollution, climatic factors, landscape change and biogeochemical cycles. The current ecological situation requires reliable solutions for relevant understanding of the phenomena in nature and preservation of favorable conditions of life and habitat.

There are several examples from Russian and international practice, when the calculations for determining critical loads were made within the developed methods. The results displayed the ceiling of reduction up to which certain hazardous substances can be emitted into land and aquatic ecosystems. The obtained scientific data formed the basis of coordinated international resolutions on reduction of emissions (Gothenburg Protocol to Abate Acidification, Eutrophication and Ground-level Ozone, The Stockholm Convention on Persistent Organic Pollutants, besides, solutions for mercury are being prepared). Modern science has made it possible to calculate the permissible flux of biogenic elements into aquatic ecosystems, which led to oligotrophication of the number of lakes (including the Great Lakes) and rivers, besides, water quality have recovered after acidification in some reservoirs of Scandinavia and North America.

The problem under discussion is the extent towards which we allow changes of certain environments. The factor of "saving the environment" should be taken into account in developing the notion of permissible environmental load, i.e. under what conditions and to what extent should the mankind limit their impact to certain environmental compartments? Obviously, the values of the ceilings can be different for conservation areas and urban lands, and this will change the requirements for limiting loads.

Conclusion

Technical progress and population growth on the planet imply the mobilization of new resources, the formation of waste products, which will inevitably continue to affect the nature. Evolution of biogeochemical cycles, ecosystems and organisms will occur in the future, and it depends on how disastrous our activities will be. In connection with the jubilee of the great thinker V.I. Vernadsky, we note that in the modern period "scientific thought as a planetary phenomenon" should focus on the prevention of the nature degradation. Development of environmental non-waste and low-waste technologies based on scientifically-proven critical loads on the biosphere and its ecosystems, rehabilitation of disturbed lands and waters is a key direction in the preservation of life-supporting conditions of our planet.

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