Environmental Pollution 26

Vladimir N. Bashkin
Editor

Biogeochemical Technologies for Managing Pollution in Polar Ecosystems

Springer

Environmental Pollution

Volume 26

Series Editor

J. Trevors
School of Environmental Sciences, University of Guelph, Ontario, Canada

Vladimir N. Bashkin
Editor

Biogeochemical Technologies for Managing Pollution in Polar Ecosystems

Springer

Editor
Vladimir N. Bashkin
Institute of Physicochemical and Biological
Problems of Soil Science RAS
Pushchino, Moscow Region
Russian Federation

Institute of Natural Gases and Gas
Technologies—Gazprom VNIIGAZ LLC
Razvilka, Moscow Region
Russian Federation

ISSN 1566-0745 ISSN 2215-1702 (electronic)
Environmental Pollution
ISBN 978-3-319-41804-9 ISBN 978-3-319-41805-6 (eBook)
DOI 10.1007/978-3-319-41805-6

Library of Congress Control Number: 2016949381

Printed on acid-free paper

This Springer imprint is published by Springer Nature
The registered company is Springer International Publishing AG Switzerland
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Contents

Part II Geo-environmental Risk Assessment

Part III New Environmentally Oriented Biogeochemical Technologies for Managing Risk of Environmental Pollution in Gas Production Areas

Introductory Paper: Biogeochemical Technologies for Managing Pollution in Polar Ecosystems

Vladimir N. Bashkin

Abstract This paper presents the editor's introductory words for the set of chapters devoted to gas industry impacts on polar ecosystems and environmental risk management. Special attention is provided to developing biogeochemical technologies for managing pollution in these ecosystems.

Keywords Gas industry impact • Environmental pollution • Polar ecosystems • Biogeochemical technologies

Increasing anthropogenic impact on the environment at local, regional and global levels requires understanding the mechanisms that determine the stability of the biosphere and its major components. The ideas of the founder of biogeochemistry V.I. Vernadsky about the universal versatility of biogeochemical cycles that determine the exchange of chemical elements between organisms and their environment on the Earth's surface have become very productive in this priority educational and scientific discipline. Biogeochemical cycling defines the role assigned to the biota in the global biological and geological activity, which gradually change the components of the biosphere. However, the environment forces as well to evolve living organisms. The quantitative parameterization of multi-scale local, regional and global biogeochemical changes due to natural and anthropogenic impacts seems to be one of the fundamental branches of modern science.

The production of hydrocarbons in the Far North, as with other types of economic activity, is accompanied by changes in the natural environment. The scope and nature of these changes depend on the intensity and specifics of ongoing impacts, determin-

V.N. Bashkin (✉)
Institute of Physicochemical and Biological Problems of Soil Sciences of Russian Academy of Sciences, Pushchino, Moscow Region 142290, Russian Federation

Institute of Natural Gases and Gas Technologies—Gazprom VNIIGAZ LLC, Razvilka, Moscow Region 142719, Russian Federation
e-mail: Bashkin@issp.serpukhov.su

V.N. Bashkin (ed.), *Biogeochemical Technologies for Managing Pollution in Polar Ecosystems*, Environmental Pollution 26, DOI 10.1007/978-3-319-41805-6_1

ing the local and regional pollution levels, this or that industrial (or secondary) geo-ecological situation and the relevant geo-ecological conditions in areas of development of deposits. For example, from the resilience of soils to thaw, as defined by species of vegetation, and in turn, by emissions of nitrogen species, which are both very important nutrients and pollutants, depends on the successful exploitation of technological equipment and infrastructure of gas and oil industry.

These criteria are largely determined by the stability of the biogeochemical structure of the Arctic ecosystems in the impacted zones of the enterprises of the gas and oil industry. Specific emissions of different gaseous compounds during extraction, preparation, transportation and processing of natural gas and associated components are the main reason of changes, which occur in biogeochemical cycles of carbon and nitrogen. This means, accordingly, that the anthropogenic load of these elements should be limited in the ranges of natural variations of different links of biogeochemical trophic chains of these cycles without irreversible changes.

It is shown that many of the changes in biogeochemical cycles of various elements occur in a narrow boundary zones between natural and anthropogenic ecosystems. These areas can be regarded as a kind of biogeochemical barriers of changing migration flows and ultimately determine the overall biogeochemical structure of the adjacent landscape. As a generalized example of the border zone can be the area between gas industry impacted ecosystems and natural ecosystems. The known environmental idea of the ecotone or "angle filter" can be referred to for understanding the boundary conditions in the articulation of their biogeochemical structure. You can offer the concept of ecotone to the biogeochemical characteristics of these territories. The huge variability of different boundary areas for the global biosphere requires the combined efforts of specialists in the field of biogeochemistry and systems ecology.

Modeling the dynamics of nitrogen and carbon in the impacted zones of the enterprises of the gas industry in Polar region allows for the analysis of the dynamics and variability of parameters of biogeochemical cycles of nitrogen and carbon in polar ecosystems for the development of technologies of risk management. It will allow to regulate in these areas the vegetation cover and to maintain its protective properties to limit the process of thawing of soils in the areas of extraction of hydrocarbons (natural gas, gas condensate and oil).

On the basis of quantitative parameterization of biogeochemical cycles of various elements in the impacted arctic and tundra ecosystems may be offered various criteria for management and sustainable development of the environment. The criteria of evaluation of the existing geoecological situation should include indicators reflecting the likelihood of occurrence and the significance of its potential adverse changes. These criteria include risk indicators, calculated using the international methodology of critical loads and the data on the volume of emissions, primarily nitrogen oxides, since these connections determine the probability of eutrophic and acidifying effects in the given impacted ecosystem.

For Polar region is also very important the development of biogeochemical norms and standards that is new, but is already actively used as a method of environmental regulation. Among these standards are the critical loads of various pollutants on terrestrial and aquatic ecosystems. Critical loads are used as officially accepted standards in a number of international conventions in Europe to limit emissions of acidifying and eutrophic sulfur and nitrogen compounds, heavy metals and persistent organic compounds. The development of new regional and national environmental standards is an important political, economic, medical and social direction of scientific research in biogeochemistry. Especially needed are studies of the impacted zones of the gas industry, both in terrestrial ecosystems, in particular in tundra and forest-tundra and marine ecosystems of the polar seas.

Thus, the study of biogeochemical indicators in gas industry impacted polar ecosystems in the Northern regions, including the simulation of risk processes and calculation of critical loads of pollutants, allows us to simulate the behavior of key elements (nitrogen, carbon) in biogeochemical cycles. This, in turn, can be used in the development and use of biogeochemical technologies, for example, for recultivation of disturbed areas, calculation of geo-ecological risk indicators and for developing techniques to manage this risk in different geo-ecological situations owing to environmental pollution.

Accordingly, this issue of Environmental Pollution Series (edited Volume) is devoted to one of the hottest topics of modern environmental science, i.e. to the environmental risk management in gas industry impacted polar ecosystems based on an alteration of biogeochemical structure of polar ecosystems where at present the most part of natural gas production is developing both in Russia and in many other countries. Being founded on the field monitoring of various parameters of biogeochemical cycles of polar ecosystems the authors suggest new biogeochemical technologies for assessing and managing environmental risk including ecological indicators of impacted ecosystems in severe climatic conditions. Some key papers focus on the biogeochemical monitoring of environmental pollution and assessing approaches to pollution risk managing at Gazprom Dobycha Yamburg LLC, the main Gazprom production subsidiary.

Accordingly, I would like to emphasize my main idea of writing this volume—this is to share our experience in estimating gas industry impacts on polar ecosystems and it seems to me that the Russian experience is quite unique due to the gas production development in this area for a long time. Of course, the authors of this volume, both experienced and young researchers, are from different companies and institutions of Russia, such as Gazprom Dobycha Yamburg, Gazprom R&D Institute of Natural Gases and Gas Technologies, Institute of Physicochemical and Biological Problems of Soil Sciences RAS, Institute of Basic Biological Problems RAS, Lomonosov Arctic Federal University, Institute of Soil Science and Agrochemistry Siberian branch of RAS, and I appreciate greatly their contributions to the given volume.

Finally, I think we are in position to present the comprehensive picture of suggested topic.

Hopefully, this issue is meant for a wide range of scientists, specialists and practitioners in ecological science, biogeochemistry and energy sector and may be quite useful to undergraduate and postgraduate students and masters, who study the fundamental principles of ecosystem sustainability at the anthropogenic impact.

Part I
Monitoring of Environmental Pollution in Gas Industry Impacted Ecosystems

Natural Biogeochemical Cycling in Polar Ecosystems

Vladimir N. Bashkin

Abstract Natural biogeochemical cycling in polar and tundra ecosystems is described. The review of literature and new data allow the author to show the approaches to biogeochemical cycling ranking in severe climate conditions based on active temperature coefficients.

Keywords Biogeochemical cycling • Polar ecosystems and ecoregions • Biogeochemical ranking • Biogeochemical regionalization

1 Introduction

In the Northern hemisphere, the area of arctic and tundra ecosystems is 3,756,000 km^2. In the southern hemisphere, these ecosystems are virtually absent. Most of the ecosystems are in Russia, Finland, Sweden, Norway, Greenland, Alaska (USA) and Canada.

These arctic and tundra zone is not really favorable for any human economic activities, especially for agriculture due to lack of heat (cumulative temperatures > 5 °C are less than 1000 °C), low soil temperatures (no higher than 10–14 °C at a depth of 10 cm), high soil acidity and amorphy, poor agrophysical properties, meagerness of humus and nourishment, and low biological activity of soils. This is compounded by short vegetation season (60–70 days) and likely frosts in summer months. As for the warm season, there is no clearly defined period with mean daily temperature of >10 °C. The forest tundra climate is severe having short and cool summers, the active season for vegetation is no longer than 50 days with temperatures of >10 °C and cumulative temperatures for the period amounting to 700–

V.N. Bashkin (✉)
Institute of Physicochemical and Biological Problems of Soil Science of Russian Academy of Sciences, Pushchino, Moscow Region 142290, Russian Federation

Institute of Natural Gases and Gas Technologies—Gazprom VNIIGAZ LLC, Razvilka, Moscow Region 142719, Russian Federation
e-mail: bashkin@issp.serpukhov.su

V.N. Bashkin (ed.), *Biogeochemical Technologies for Managing Pollution in Polar Ecosystems*, Environmental Pollution 26, DOI 10.1007/978-3-319-41805-6_2

800 °C. The soils are undeveloped, tight, waterlogged and poorly aerated, have high acidity and low temperatures, which in total results in low biological activity, since the plant nutrients in the soil are scarce.

It is well known that the Russian Federation accumulates the major natural gas reserves and the largest part of these reserves is located in Polar region with severe natural conditions and vulnerable environment. Monetization of these reserves and gas supplies to both domestic and foreign consumers require using sustainable development approaches based on unified environmental, social and economic principles. These principles should be the grounds for industrial activity of all gas companies.

Accordingly, on a basis of sustainable development principles no harmful influence should be given to natural ecosystems during gas and oil production. This means that the anthropogenic loads must be in the limits of natural deviations of biogeochemical food chains (Bashkin 2002). Thus the aim of this paper is to describe the natural features of biological and biogeochemical cycling in polar ecosystems.

2 Biological and Biogeochemical Cycling in the Arctic Regions

2.1 Biological Cycling

In lowland tundra, the biological cycle occurs in conditions of long polar day: the long summer time is effective for photosynthesis due to the high energetic light and plants have adapted to this. "Long day plants" are poorly developed in low latitudes with short day. Thanks to the long day the amount of solar radiation in the lowland tundra is the same as in southern taiga, but the temperature in summer is much lower. Low air temperature and soils limit biological cycle, these are the cause of many features, in particular, development of xeromorphic plants. Deficiency of heat is related with so called "waves of life": in years with warmer summers increasing the annual production of living matter. Some plants bloom only in favorable years, such as fireweed in the Arctic tundra.

Biomass in the Arctic tundra varies widely—from 0.40 to 3.00 t/ha, most of it concentrated in the roots (70–80 %). In shrub tundra these values can be much higher. Plants grow slowly: lichens for the year increase by 1–10 mm, the juniper on the Kola Peninsula with a trunk diameter of 83 mm has 544 annual rings. However, it affects not only the adverse influence of low temperatures, but also the poverty of the environmental nutrients. The annual increase is 1.0 t/ha for the Arctic tundra and 25—for shrub one.

Due to the low temperature decomposition of remains of organisms in the tundra is slow, many groups of microorganisms do not function or work very poorly (bacteria that break down cellulose, etc.). This leads to the accumulation of organic matter on the surface and in the soil. In the litter accumulates 2.5—83.5 t/ha with an annual litter fall of $n \times 10^{-1}$–5.0 t/ha. The value of the ratio of the total mass of the annual litter fall, which characterize the intensity of decomposition of plant residues (innerecosystem biological cycle, C_b) ranges from 100 to 17. This contributes to the accumulation of organic matter in the upper layers of the soil profile.

2.2 *Biogeochemical Cycling*

2.2.1 Arctic Ecosystems

Depending on the absorption of macro- and microelements by the plants the involvement of these chemical elements in biogeochemical cycling is in different ways. The ratio of the concentration of elements in plants to their concentration in water extracts from soil-forming rocks (the value of the coefficient B_x by Kasimov 1995), shows that in the Arctic ecosystems iron and manganese to the greatest extent are absorbed by plants. The coefficient of biological absorption, A_x (Perelman and Kasimov 1999) can serve as an indicator of this absorption. The magnitude of A_x for Fe and Mn are in the range from $n \times 10^2$–$n \times 10^3$, whereas for Zn, Cu and Ni, these values equal approximately to $n \times 10^1$. It should be emphasized that high concentrations of iron and manganese are usually determined in dead organic matter (mortmass) of peat bogs (Perelman and Kasimov 1999).

The removal of elements from soil solution by plant uptake, leaching and remobilization in the composition of soil organic matter is balanced by a new entry of chemicals that support the permanence of biological and biogeochemical cycle. The main inputs of chemical elements in Arctic ecosystems is due to the marine aerosols deposited on the surface of the soil and weathering of rocks. For example, on the island of Spitsbergen atmospheric inputs of various elements are characterized by the following values (Table 1).

You can compare these values with the flows of the considered metals in biogeochemical cycles. Biological productivity of the Arctic ecosystem, developing on low terraces of the Spitsbergen Island, is shown in Table 2.

Table 1 Air intake elements in the ecosystem of the island of Spitsbergen, mg/year for 100 mm of precipitation (Dobrovolsky 1994)

Element	Fe	Mn	Zn	Cu	Ni
Input	27,500	800	31,100	900	300

Table 2 Biological productivity of the Arctic ecosystems of the Spitsbergen island (Manakov 1972)

Productivity	ton/ha
Total biomass of living plants	2.9
Total mortmass	9.6
Net annual production	0.6

It can be noted for comparison that the annual increase in the biomass of polar willow (Salex arctica) on the Islands of the Canadian archipelago, located at 75°N, is about of 0.03 t/ha (Warren 1957).

Biogeochemical flows of chemical elements in Arctic ecosystems are given in Table 3. For iron and manganese they are much higher than their inflow with atmospheric precipitation. At the same time, the supply of copper balances its annual consumption, and for zinc is even in excess. All these metals are essential elements and their flow from rainfall can be considered as a positive factor for the functioning of polar ecosystems. Excessive intake of lead, for which an unspecified physiological and biochemical functions, can be considered as pollution. However, a significant amount of lead can be quickly immobilized in the composition of dead organic matter and derived from the biogeochemical cycle.

For subordinate landscapes the input of the nutrient elements is due to the lateral inflows from surface and subsurface runoff. Ecosystems of marshy glacial valleys can get significant amounts of additional nutrients from overlying geochemically subordinate landscapes. This increases the productivity of the respective wetland ecosystems in 3–4 times in comparison with the eluvial landscape ecosystems, and the consequent biogeochemical fluxes of elements. For example, accumulation of elements in dead peat organic matter of waterlogged valleys was estimated as the follows: Fe, $n \times 10^{1}$ kg/ha, Mn, 1–2 kg/ha, Zn, 0.1–0.3 kg/ha, Cu, Pb and Ni, $n \times 10^{-2}$ kg/ha.

2.2.2 Biogeochemical Cycling in Tundra Ecosystems

Tundra landscapes and associated ecosystems occupy the northern strips of the Eurasian and North American continents bordering the Arctic seas. The climatic conditions of the tundra will allow ecosystems to achieve higher productivity. In

Table 3 Biogeochemical flows of chemical elements in ecosystems of the Spitsbergen island (Dobrovolsky 2003)

Metals	Mean plant content, ppm on dry mass	Metal fluxes, g/ha/year			Precipitation input[a], g/ha/year
		In living plants	In mortmass	In annual plant increase	
Fe	2000.0	5800.0	19,200.0	1200.0	82.5–110.0
Mn	150.0	435.0	1440.0	90.0	2.4–3.2
Zn	60.0	174.0	576.0	36.0	93.3–124.4
Cu	6.3	18.3	60.5	3.8	5.1–6.8
Ni	4.3	12.5	41.5	2.6	0.9–1.2
Pb	3.7	10.7	35.5	2.2	2.7–3.6
Co	1.0	2.9	9.6	0.6	0.9–12

[a]Note: Admission with atmospheric deposition was calculated at 300 and 400 mm per year in accordance with annual precipitation on the island of Spitsbergen and the content of metals in sediments is shown in Table 1

Table 4 The partition of biomass in tundra ecosystems, t/ha (Rodin and Bazilevich 1965)

Biomass type	Living plant biomass	Mortmass	Net annual production	Annual litter fall
Mass	28	83	20.4	20.3

tundra ecosystems the higher activity of biogeochemical cycles of various elements is observed as compared with the Arctic ecosystems. The mosses, lichens and herbaceous plant species are predominant in the northern part of the tundra, and shrubs—in the southern part.

The biomass of tundra ecosystems varies from 4–7 t/ha for moss-lichen tundra to 28–29 t/ha of dry weight in shrub tundra. In the northern tundra, the ratio of live and dead biomass approximately equal to 1:1, and to the south, living biomass is smaller than dead plant remains mass. The average values of the organic matter distribution in tundra ecosystems are shown in Table 4.

Edaphic microflora is more diverse in tundra ecosystems, and the number of microbial cenosis is characterized by higher values than in the soils of arctic ecosystems. The number of bacteria varies from 0.5×10^6 to 3.5×10^6 cells per gram in the upper soil layers.

The content of ash elements and nitrogen is characterized by similar values in the biomass of tundra ecosystems. The highest concentrations, >0.1 % of dry weight, are typical for Ca, K, Mg, P and Si. It is possible to note an increased content of iron, aluminum and silicon in the aboveground parts of plants (Vasilevskaya 1996, 1998).

Tundra ecosystems are formed on different soils. In conditions of well-drained slopes and watershed surfaces brown acidic tundra soils are formed. Characteristic features of these soils are the accumulation of undecomposed plant residues and the formation of the peat horizons. The underlying soil layers are poorly differentiated. The humus content in the thin humus horizon varies from 1 % to 2.5 % with a predominance of soluble fulvic acids. This determines the acidic reaction of soil, $pH < 5.0$. Acidic geochemical conditions favor the migration of many metals, phosphorus, nitrogen and several alkaline-earth elements. Migration of chemical elements mainly occurs in the form of the Me-organic or P-organic complexes.

In low relief with poor permeability of soil and grounds there is often a shortage of oxygen, which leads to the formation of tundra gley soils (*Gelic Regosol*). Gley horizon of these soils enriched (in order) by inclusions of precipitated gels of oxides of trivalent iron.

Biogeochemical cycle of nitrogen is about 50 kg/ha/year. Similar values are shown for the amounts of mineral elements, 47 kg/ha/year. The corresponding values of various macro- and micronutrients are given in Table 5. The fluxes of chemical elements per area unit in tundra ecosystems are not proportional to the uptake by plants. Some elements such as Zn and Cu, are selectively absorbed, other elements, Ti, Zr, V or Y, are adsorbed passively, depending on their concentration in soils.

Where soluble mineral compounds come to the landscapes from the outside, biogeochemical cycling increases, the vegetation becomes more luxuriant, the role of flowering plants increases and the role of mosses and lichens is reduced. Such conditions are created in the floodplains of some rivers, enriching in a flood period

Table 5 Annual biogeochemical fluxes of chemical elements in dwarf shrub-moss tundra ecosystem (Dobrovolsky 1994)

Element	Symbol	Plant uptake fluxes, kg/ha/year
Nitrogen	N	50
Iron	Fe	0.188
Manganese	Mn	0.226
Titanium	Ti	0.031
Zinc	Zn	0.028
Copper	Cu	0.0071
Zirconium	Zr	0.0070
Nickel	Ni	0.00188
Chromium	Cr	0.00165
Vanadium	V	0.00141
Lead	Pb	0.00116
Yttrium	Y	0.00070
Cobalt	Co	0.00047
Molybdenum	Mo	0.00043
Tin	Sn	0.00024
Gallium	Ga	0.00005
Cadmium	Cd	0.00003
Mean plant ash content, %		2.0
Total ash elements uptake by plants, kg/ha/year		47

by fertile silt, on the rookeries, at space camps, on the flat bottoms of lakes around the Arctic foxes' holes, etc. In some tundra ecosystems the high thickets of flood-plain grass create the impression of the more southern areas. Tundra wet meadows also have a high grass, they are characterized by an abundance of grasses, the presence of legumes that are missing in the offline landscape. Respectively meadow tundra ecosystems also develop along streams and rivers at the bottom of former lakes, pipelines, etc.

In Kamchatka peninsula the dense grass cover is characteristic for the tundra ecosystems, which periodically covered by volcanic ash. Therefore, climate is not the direct cause of the wide development of mosses and lichens in acidic gley southern tundra—the main reason is owing to the low content of nutrients in the soil and low speeds of depressive biogeochemical cycle.

2.3 Biogeochemical Regionalization of Polar Ecosystems

Depending on climate, geological bedrock, soil and vegetation cover, hydrology, and topography, the global ecosystem is divided into various ecoregions and ecozones (see for example, Bailey 1998). Within of these structural units of the biosphere, the spatial organization of the global ecosystem is manifested in the form of characteristic features of the biogeochemical cycles of different elements. This equally applies to the ecosystems.

2.3.1 Parameterization of the Biogeochemical Cycle

Biogeochemical cycles in different ecosystems are largely determined by the biota, especially the processes of primary productivity and decomposition of dead organic matter. Biogeochemical cycles represent the cumulative display settings of the circulation of substances between the various components of the biosphere—soils, surface and ground waters, sediments, biota and the atmosphere (Fig. 1).

Soil, geobotanical, geological, and overall ecosystem regionalization is the basis of biogeochemical zoning (Fortescue 1980; Glazovskaya 1997, 2002; Bazilevich 1993; Ermakov 1993; Bashkin and Bailey 1995; Bashkin and Kozlov 1999; Perelman and Kasimov 1999; Bashkin 2002, 2004, 2006, 2008, 2009; Kasimov and Klige 2006). The combination of these types of regionalization with quantitative indicators of biological, geochemical and hydrochemical cycle allows us to calculate the velocity of the biogeochemical cycle. It is shown that in the most parts of the Earth's surface the actual length of the various processes that determine the circulation of chemical elements (chemical, biological, microbiological, geochemical, and biogeochemical processes) depends on the duration of the winter period, when the intensity of these processes is significantly reduced or completely suspended within 6–10 months. It is also known that the effect of any pollutants on these processes occurs only during the spring and summer time. The duration of this impact can be characterized by the active temperature factor, C_t, which is the ratio of the sum of active temperatures >5 °C to the total amount of annual temperatures.

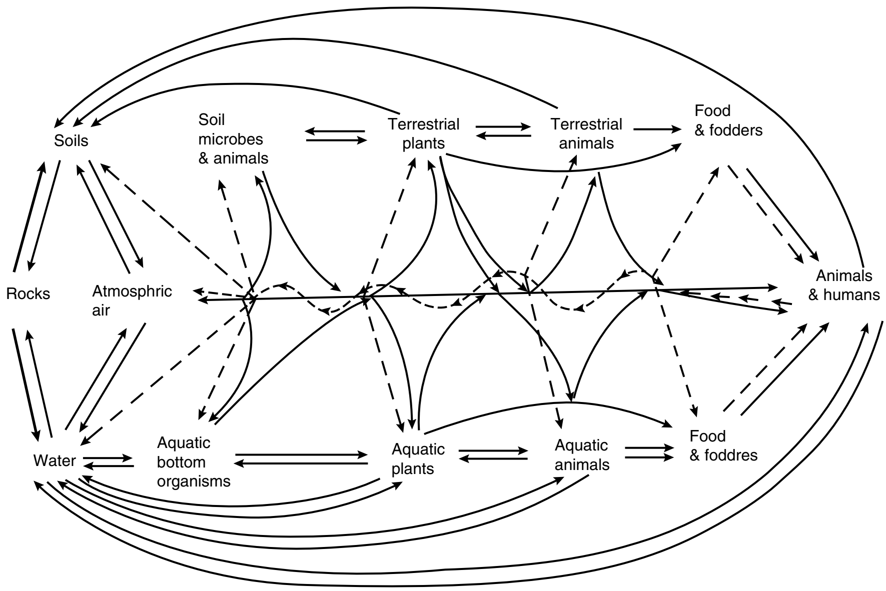


Fig. 1 The general scheme of biogeochemical food webs in terrestrial ecosystems

For the influence of temperature on the processes of biological absorption of elements is proposed using the coefficient of biogeochemical cycles, C_x, which is calculated as the product of the coefficient of inner ecosystem biological cycle, C_b, which is equal to the ratio of litter mass to the mass of annual litter fall and the rate of active temperatures:

$$C_x = C_b \times C_t.$$

Its use allows taking into account the influence of the period of active temperatures on the rate of biogeochemical cycles in different ecosystems. The coefficient of biogeochemical cycling can be used for correction of the values of inner ecosystem biological cycle, C_b.

Table 6 shows the combination of soil temperature and biogeochemical conditions in various polar and tundra geographic regions of the Earth. It is represented ecosystem types, soil types according to the classification of FAO, the coefficients of inner ecosystem biological cycle, C_b, active temperature, C_t, and biogeochemical cycles, C_x.

To understand these approaches it is necessary to pay attention to the principles of the global regionalization of the parameters used.

The coefficients of active temperatures, ranked in accordance with the main climatic zones are shown in Table 7.

The coefficients of biogeochemical cycles, C_x, for all geographic regions were ranked to determine the type of biogeochemical cycle and these grades are

Table 6 The coefficients of inner ecosystem biological cycle (C_b), active temperatures (C_t) and biogeochemical cycles (C_x) in different soil-ecosystem and geographical regions of the Earth

Ecosystems	FAO main soil types	Geographic regions (Glazovskaya 1978)	Index	No	C_b	C_t	C_x
			See Glazovskaya 1984				
Primitive Arctic desert and tundra	Litosols, Regosols	North American	1_1	1	75.0	0.07	5.3
		Eurasian	1_2	2	75.0	0.07	5.3
Tundra	Cryic Gleysols, Histosols, Humic Podzols	North American	2_1	3	18.0	0.15	2.7
		Eurasian	2_2	4	18.0	0.15	2.7

Table 7 Ranking of indicators of a temperature mode to assess the duration of biogeochemical reactions

Rank	Temperature regime	Coefficient of active temperature, C_t
1	Arctic	<0.25
2	Boreal	0.26–0.50
3	Sub-Boreal	0.51–0.80
4	Mediterranean	0.81–0.99
5	Subtropical and Tropical	1.00

Table 8 Ranking of indicators of the biogeochemical cycle to estimate rates of migration in different ecosystems (Bashkin 2002)

Rank	Biogeochemical cycling	Coefficient of biogeochemical cycling, C_x
1	Very intensive	<0.4
2	Intensive	0.5–1.4
3	Moderate	1.5–2.5
4	Depressive	2.6–4.9
5	Very depressive	>5.0

shown in Table 8. Five types of biogeochemical cycle are selected: very intensive, intensive, moderate, depressed, and very depressed.

Intensive and very intensive type of biogeochemical cycle occurs in tropical and desert ecosystems where rapid biological turnover under conditions of high temperature of the growing season. The moderate type of circulation is typical for steppe, forest-steppe and sub-boreal forest ecosystems, whereas in the boreal taiga forests the depressive type of biogeochemical cycle is dominated. Very depressive type is in tundra and arctic ecosystems.

Using the above described approaches, let us to consider arctic and tundra ecosystems on different continents.

2.3.2 Regionalization of the Biogeochemical Cycle

Eurasia

On the vast territory of Eurasia in all climatic zones are all types of ecosystems, from Arctic deserts to tropical rain forests (Fig. 2).

Primitive Arctic desert and tundra ecosystems are found in the Eurasian geographical region, which occupies the most Northern part of the Asian Arctic and includes the northern large island of the North Land and a number of small neighboring islands. Biogeochemical cycle in these ecosystems is characterized by Arctic hydrothermal regime, including very low temperatures, little annual rainfall (50–150 mm) and primitive shrub, algae and lichen vegetation. Biogeochemical cycling can be defined as very depressed, which includes a long period of mineralization of organic residues (from 10 to 50 years or more), and a short relative period of annual active temperatures >5 °C (C_t is equal to 0.05–0.10). The predominant soils are *Regosols* and *Litosols*, in the crevices, Histosols.

Tundra ecosystems are widespread in the Eurasian geographical region on gley and podzolic soils (*Podzols Distric*, *Cryic Gleysols*, *Histosols*, *Regosols and Litosols*). Biogeochemical processes in these soils are characterized with low quantity of heat, short but intense period of active temperatures (the average value C_t is equal to 0.15), wide distribution of permafrost and a small amount of precipitation, low biological and microbiological activity and low rate of chemical weathering.

The average value of C_b is equal to 18 (15–50), in combination with low annual mean temperature it leads to a very depressive type of biogeochemical cycle. However, the prolonged winter period contributes to the accumulation of various pollutants in the snow cover with their explosive impact on the ecosystem during the spring-summer period.

North America

In the North, in the Arctic and the subarctic zones, the annual radiation balance is 0–10 kcal/cm^2 (Glazovskaya 1978; Bailey 1998; Bashkin 2002).

Tundra ecosystems (North American tundra geographic region) cover the northern coast of the continent and adjacent islands of the American archipelago (Fig. 2).

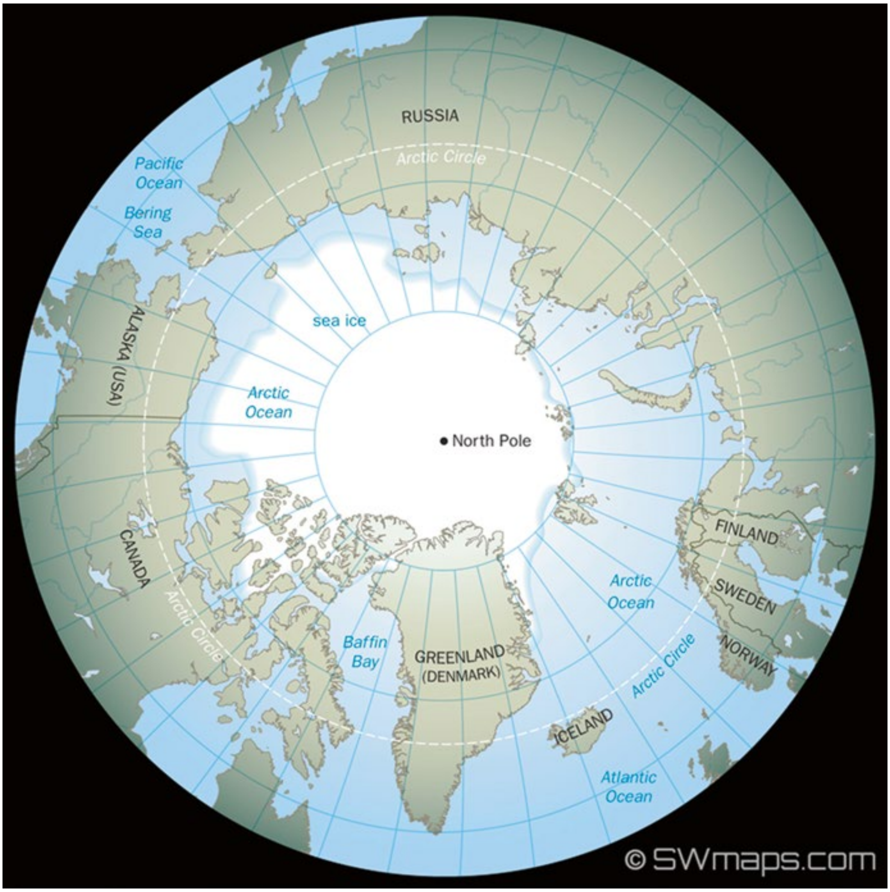


Fig. 2 Northern polar region of Earth (SWmaps.com)

In the North this region is bordered by the Arctic deserts and in the South—boreal taiga forests ecosystems. As in Eurasia, the southern boundary of tundra ecosystems varies with the height above the sea level. On the Labrador peninsula, washed by cold currents, and on the coast of cold Hudson Bay, tundra ecosystems penetrate as far South as 54°N. To the West of Hudson Bay, with an increase in the continentality of climate, the boundary between tundra and boreal taiga forest ecosystem is shifted to the North. On the Meridian of the Great lakes it lies slightly North of the Arctic circle, near the estuary of the Mackenzie river, the boundary extends a maximum North—to 68.5°N. The Northern part of Alaska is occupied by tundra ecosystems, and along the coast of the Chukchi Sea the border of the tundra shifts back to the South. Biogeochemical cycling in these tundra ecosystems is similar to those described for the Eurasian continent (see Table 6).

3 Conclusions

Thus, the natural biogeochemical cycling is described for understanding the natural parameters in polar and tundra ecosystems. The review of literature and new data allow us to show the approaches to biogeochemical cycling ranking in severe climate conditions based on active temperature coefficients. Finally, the given data base is a key for managing environmental pollution in gas industry impacted ecosystems on a basis of their biogeochemical ranking and biogeochemical regionalization.

References

Bailey, R. G. (1998). *Ecoregions: Ecosystem geography of oceans and continents*. New York: Springer. 203pp.

Bashkin, V. N. (2002). *Modern biogeochemistry*. Dordrech, London, Boston: Kluwer Academic Publishers. 572pp.

Bashkin, V. N. (2004). *Biogeochemistry*. Moscow: Scientific World. 584pp.

Bashkin, V. N. (2006). *Modern biogeochemistry: Environmental risk assessment* (2nd ed.). New York: Springer Publishers. 444pp.

Bashkin, V. N. (2008). *Biogeochemistry*. Moscow: Higher school. 424pp.

Bashkin, V. N. (2009). *Modern biogeochemistry: Environmental risk assessment* (2nd ed.). China: CIP. Chinese translation, 268pp.

Bashkin, V. N., & Bailey, R. G. (1995). Global map of ecoregions: Biogeochemical and soil approaches. *Eurasian Soil Science, 3*, 365–374.

Bashkin, V. N., & Kasimov, N. S. (2004). *Biogeochemistry*. Moscow: Scientific World. 634pp.

Bashkin, V. N., & Kozlov, M. Y. (1999). Biogeochemical approaches to the assessment of East Asian ecosystem sensitivity to acid deposition. *Biogeochemistry, 47*, 147–165.

Bazilevich, N. I. (1993). *Biogeochemistry of natural zones of the USSR*. Moscow: Nauka. 423pp.

Dobrovolsky, V. V. (1994). *Biogeochemistry of the world's land*. Moscow/Boca Raton–Ann Arbor–Tokyo–London: Mir Publishers/CRC Press. 362pp.

Dobrovolsky, V. V. (2003). *Fundamentals of biogeochemistry*. Moscow: Academia. 400pp.

Ermakov, V. V. (1993). Biogeochemical mapping of continents. In V. N. Bashkin, E. V. Evstafieva, & V. V. Snakin (Eds.), *Biogeochemical fundamentals of environmental regulation* (pp. 5–24). Moscow: Nauka.

Fortescue, J. A. C. (1980). *Environmental geochemistry. A holistic approach*. Berlin: Springer. 347pp.

Glazovskaya, M. A. (1978). *Soils of the world, part 1 and 2*. Moscow: MSU Press. 427pp.

Glazovskaya, M. A. (1984). *Soils of the world*. New Delhi: American Publishing Co.. 401pp.

Glazovskaya, M. A. (1997). *Methodological bases of estimation of ecological-geochemical soil sustainability to anthropogenic influences*. Moscow: MSU Publishing House. 102pp.

Glazovskaya, M. A. (2002). *Geochemical fundamentals of typology and methodology of research of natural landscapes*. Smolensk: Ojkumena. 288pp.

Kasimov, N. S. (1995). *Ecogeochemistry of urban landscapes*. Moscow: MSU Press. 336pp.

Kasimov, N. S., & Klige, R. K. (2006). *Modern global changes of natural environment* (Vol. 1). Moscow: Nauka. 200pp.

Manakov, K. N. (1972). *Biological cycle in arctic and tundra ecosystems*. Moscow: Nauka. 146pp.

Perelman, A. I., & Kasimov, N. S. (1999). *Landscape geochemistry*. Moscow: Astreya-2000. 763pp.

Rodin, L. E., & Bazilevich, N. I. (1965). *Organic matter dynamics and biological cycles of ash elements and nitrogen in main types of vegetation of the Earth*. Moscow-Leningrad: Nauka. 251pp.

SWmaps.com.

Vasilevskaya, V. D. (1996). Assessment of the stability of permafrost-affected tundra soils to anthropogenic influences. *Bulletin of Moscow University. Ser. 17, Soil Science, No. 1*, 27–35.

Vasilevskaya, V. D. (1998). Functioning of tundra soils in the permafrost microrelief system. In V. D. Vasilevskaya (Ed.), *Problems of regional ecology, geography and cartography of soils* (pp. 154–175). Moscow-Smolensk: SSU Publishing House.

Warren, W. J. (1957). Arctic plant growth. *Advancement in Science, 143*, 383–388.

Gas Industry Impacts on Natural Ecosystems

Vladimir N. Bashkin, Rauf V. Galiulin, Pavel A. Barsukov, and Anatoly K. Arabsky

Abstract This paper is devoted to assessing the gas industry impacts on surrounding tundra ecosystems. The relevant loading of pollutants emitted by production activity of gas company "Gazprom Dobycha Yamburg LLC" is accounted using both the retrospective pollutant emission database and field monitoring results. Perennial analyses of emitted pollutant loading showed that priority atmospheric pollutants for the zone of influence of the production facilities of "Gazprom Dobycha Yamburg" LLC are oxides of nitrogen.

Keywords "Gazprom Dobycha Yamburg" LLC • Atmospheric pollutants • Loading • Oxides of nitrogen

1 Introduction

The need for permanent monitoring of biogeochemical cycles and ecological situation in the impacted zones of gas and oil industry enterprises is primarily due to the fact that the production of hydrocarbons take place in the Arctic ecosystems: the

V.N. Bashkin (✉)
Institute of Physicochemical and Biological Problems of Soil Sciences of Russian Academy of Sciences, Pushchino, Moscow Region 142290, Russian Federation

Institute of Natural Gases and Gas Technologies—Gazprom VNIIGAZ LLC, Razvilka, Moscow Region 142719, Russian Federation
e-mail: vladimir.bashkin@rambler.ru

R.V. Galiulin
Institute of Basic Biological Problems of Russian Academy of Sciences, Pushchino, Moscow Region 142290, Russian Federation

P.A. Barsukov
Institute of Soil Science and Agrochemistry of Siberian Branch of Russian Academy of Sciences, Novosibirsk 630099, Russian Federation

A.K. Arabsky
Gazprom Dobycha Yamburg LLC,
Novy Urengoy, Yamalo-Nenets Autonomous District 629300, Russian Federation

V.N. Bashkin (ed.), *Biogeochemical Technologies for Managing Pollution in Polar Ecosystems*, Environmental Pollution 26, DOI 10.1007/978-3-319-41805-6_3

subzone of the southern and typical tundra. The high sensitivity of these ecosystems to any anthropogenic influences (disturbances) is well known and described in the scientific literature (Bashkin et al. 2012). One of the most important effects is the additional intake of various elements and their compounds in tundra ecosystems (soil and plants) due to their emission from various industrial sources in the extraction and transport of hydrocarbons. Some of these elements/compounds may have an inhibitory effect on the biota of tundra ecosystems, and some, on the contrary, can play the role of mineral nutrients for tundra plants and many groups of soil microorganisms. The latter, in its effect, can have a very greater influence on changes in biogeochemical cycles and their separate parts—plant productivity, biodiversity, disturbance of cycles of carbon, nitrogen, phosphorus and sulfur, the changes in the abundance and species diversity of soil microorganisms. It is known that even a small addition of nutrients in tundra ecosystems have major implications in biogeochemical cycles (Mack et al. 2004; Deslippe et al. 2005; Stapleton et al. 2005; Bargagli 2005; Bashkin 2006, 2014; Nemergut et al. 2008). In this case, the received data are ambiguous. A number of researchers note that, in particular additional nitrogen input in the form of various oxides of nitrogen (NO_x) from the atmosphere into the soil increases the content of available to plants and heterotrophic soil microorganisms nitrogen due to the transformation of nitrogen oxides into nitrates (Bashkin and Priputina 2010). As a result, it significantly increases the productivity of plant communities in tundra ecosystems and thus contributes to further sequestration of carbon dioxide from the atmosphere in the soil–plant system (Bashkin 2006; Gorham 1991; Hobbie and Chapin 1996; Mckane et al. 1997; Jonasson et al. 1999; Sturm et al. 2001; Shaver et al. 2001; Bret-Harte et al. 2002; Bashkin 2002). However, there is evidence that in the medium term (10–20 years) additional intake of nutrients in tundra ecosystems causes a decrease in stocks of carbon and nitrogen in the soil–plant system due to the increased mineralization of soil organic matter in tundra soils (Mack et al. 2004). It can be assumed that the effect of atmospheric deposits, formed during the production of hydrocarbons, on tundra ecosystems can vary considerably depending on the type of plant communities (lichen tundra, moss-herbaceous tundra, shrub tundra, etc.) and the ratio of hard- and easy mineralized soil organic matter and its total content (Safonov et al. 2008). The latter will significantly depend on vegetative components of ecosystems and from the parent rock. For example, in studies conducted in various plant communities of the tundra zone of Alaska a different effect of additional nutrient elements in the total plant biomass was marked (Gough et al. 2002). The need for biogeochemical studies in different tundra ecosystems is due to the fact that soil and vegetation of this area are very diverse and represented a wide range from sandy soils with lichen vegetation (alectoric tundra) to heavy-tundra-gley ones with shrub-lichen vegetation within the southern tundra subzone and dwarf birch-lichen larch woodland moss and the dwarf shrubs communities within the forest-tundra zone. Also various options for polygon-hill mires on peat soils are widespread.

Works on integrated impact assessment of atmotechnogenic pollutants on tundra ecosystems, which differ in soil properties and composition of plant communities, will serve the purpose for a long period of biomonitoring of environmental status and reversible and irreversible changes of biogeochemical cycles of various elements in the impacted zones of the enterprises of the gas industry. The prevention of irreversible changes of biogeochemical cycles is a consequence of the trend of minimization of anthropogenic impact in the development of gas and gas condensate fields. The monitoring data including the biological and geological parameters of ecosystems can be used as input for modeling biogeochemical cycles of various elements, behavior and dynamics of nitrogen and carbon in ecosystems of tundra and subarctic zones in the zones of influence of various objects of "Gazprom" JSC, in particular, "Gazprom Dobycha Yamburg" LLC, which will be discussed below.

2 Atmospheric Pollutants

The pollutant means a substance or compound, that being loaded into natural environment in quantities greater than the background values, thereby cause chemical pollution. In turn, this pollution is accompanied by reversible or irreversible changes in biogeochemical cycles of ecosystems. Here are considered atmospheric pollutants of anthropogenic origin (unlike the pollutants of natural origin) and the nature of receipt in the environment is corresponding to the primary inputs directly from pollution sources (unlike the secondary, formed from the primary objects in the environment as a result of biogenic and abiotic transformations). In terms of impacts on different natural environments can be distinguished the following polluting species:

– acid (sulfur and nitrogen);
– eutrophication (phosphorus and nitrogen);
– pollutants (heavy metals, organic compounds, petroleum products).

When assessing contamination of ecosystems by pollutants, monitoring details of atmospheric deposition in the studied area are extremely necessary. For the Northern part of Western Siberia air migration of substances was evaluated on the basis of the analysis of the composition of plants, sequestering atmospheric deposition (epiphytic and ground lichens), and composition of the snow cover (Moskovchenko 2010). According to the results, almost everywhere the content of heavy metals in lichens corresponds to the level characteristic to the background areas (Nieboer et al. 1978). However, the spatial variability of composition is significant. In the Arctic and subarctic tundra heavy metal concentrations in the tissues of lichens have the minimal values. The maximal depositions of lead, zinc, copper were noted in the Southwestern districts of the Tyumen region adjacent to the Ural industrial area. Thus, there is a latitudinal gradient deposition of heavy metals, due to differences in the level of industrial development and population density of the Northern and southern territories, and an increase in precipitation, stripping aerosols. This tendency of reducing the deposition of metals at high latitudes has obviously circumpolar distribution, as in the territory of the Canadian Arctic also were found the existence of a latitudinal gradient, with a clear tendency for Pb content decreasing in lichens with increasing latitude (France and Coquery 1996).

Conclusion on minor technogenic influence of deposition was confirmed by the analysis of snow cover. Snow precipitations coming in the winter on the territory of the taiga zone of Western Siberia are characterized by low mineralization, slightly acidic or neutral reaction (pH 5.1–6.5) and contain a small amount of solids (2–15 mg/l). The level of sulfate is approximately twice less than in the industrial areas of the Urals. The flow of nitrogen is small and corresponds to the indices of the neighboring regions (Semenov 2002). Within the deposits the increased concentrations of petroleum products were observed. The content of heavy metals at background sites is small and corresponds to the level typical for the polar and subpolar regions of Eurasia and North America. The impact of oil production results in increased content of Ni, Zn, Cu and Hg concentrations, which exceed the background level by 1.5–4.8 times (Moskovchenko 2010).

In tundra ecosystems due to low buffering capacity and low content of base cations in the soils and the low biological productivity of biocenoses, natural objects are sensitive to loading of acid-forming and eutrophic sulfur and nitrogen compounds (SO_2, NO_x). Other significant chemical hazards to ecosystems are elements with high background content in the soils of the territory and which are being additionally accumulated in soil, vegetation and snow cover during aerogenic pollution. According to long-term monitoring of the geological environment, these elements are Mn, Ni, Cu, Al, Fe, Ti, V, Zn, Co, Cr, Pb (Demidova 2007). Often, however, as priority pollutants to assess atmotechnogenic pollution, the researchers stopped the choice on the sulfur, nitrogen and three heavy metals: Pb, Cu and Zn.

The most significant sources of atmospheric pollutants on the territory of "Gazprom Dobycha Yamburg" LLC are the units of complex preparing of gas (UCPG), which is complex process equipment and ancillary systems ensuring the collection and processing of natural gas and gas condensate in accordance with the requirements of industry (GRL) and state (GOST) standards. Raw material unit is natural gas and gas condensate fields.

In the area of the impact zone as the primary key source of air pollution, UCPG-2 (unit-2) was chosen due to the fact that it is the oldest unit, characterized by close to the maximum values of the emissions of pollutants in comparison with other units on the territory of "Gazprom Dobycha Yamburg" LLC (Figs. 1 and 2). The date of entry of UCPGs into operation: unit-2—September 1986; unit-1—June 1987; unit-5—January 1988; unit-6—September 1988; unit-3—July 1989; unit-1B—March 1991 and unit-3B—October 1996.

3 Risk of Atmospheric Pollutants Impact on Person

It is known that pollution of the air environment in the gas industry as a result of emergency emissions and leak of natural gas perhaps under the following circumstances: in the course of drilling and/or operation of gas wells; at deviations during

Fig. 1 View of unit-2 from North to South

Fig. 2 View of unit-6 from West to East

technological processes of gas preparation for distant transportation; violation of the rules of technical operation of gas pipelines; mechanical damages, defects of a pipe and gas equipment; defect of installation and construction works, etc. As for pollution of the air environment by products of natural gas burning in the form of carbon oxides (oxide and carbon dioxide), nitrogen oxides (oxide and dioxide of nitrogen), sulfur dioxide and benz(a)pyrene, it occurs when functioning gas-torch installations, compressor stations, and also by production of a complex of works connected with arrangement and operation of natural gas fields (Andreev et al. 2011).

In this regard it is important to represent risk of natural gas and products of its burning impact on person and need of control of the air environment pollution by these substances in the gas industry. The last is considered one of important practical problems of biogeochemistry as science, along with biogeochemical division into districts of localization of the gas industry objects territories for purpose of identification of biogeochemical endemic (endemic diseases). However conducting control of pollution of the air environment becomes complicated that it as the natural system is very mobile in space and time owing to what products of emissions of the gas industry can be transferred to long distances (to tens of kilometers). Besides, these products can get to soil, natural waters, on growing plants, leading to pollution of such trophic chains as soil-plant-person, soil-plant-animal-person, water-person, water-fish-person. Thus the accounting of the geoecological situation connected with pollution of trophic chains gains especially vital value as economic activity of indigenous people on the Far North is based especially on occupation by reindeer breeding, hunting and fishery, first of all, providing with food.

Meanwhile the risk of natural gas and products of its burning impact is defined on person by the following factors: concentration of these substances in the air environment of a working zone, that is space up to 2 m high over the level of a floor or platform on which there are places of continuous or temporary stay of the working; concentration of these substances in the air environment of occupied places where the gas industry objects are located; meteorology conditions during emergency emission, leak or burning of natural gas in the occupied places; land relief. So, the considerable accumulation of gas in the air environment resulting from accident on a well, break of the gas pipeline or depressurization of processing equipment can be promoted by calm weather and low-lying part of locality.

Meanwhile the main component of natural gas—methane (70–99 % on volume) has toxic impact on the person that in usual conditions is defined by a lack of oxygen. So, the accumulation of methane in air to 25–30 % corresponding to decrease in the content of oxygen in it with 21 to 15–16 % is followed by distinct signs of oxygen starvation: pulse increase, increase in volume of breath, weakening of attention, violation of movement coordination. As for other components of natural gas, ethane is capable to cause a condition of braking of the central nervous system, and intoxication by propane and butane leads to a lethal outcome, owing to heart violations and oedema of lungs.

Such component of natural gas as hydrogen sulfide, containing in natural gas (1.6–26.3 % on volume) represents gaseous substance with a characteristic smell of rotten eggs (Boev and Setko 2001). The threshold of olfactory feeling of hydrogen sulfide is in limits of 0.012–0.03 mg/m^3, a notable smell—1.4–2.3 mg/m^3, a considerable smell—at 4 mg/m^3, sickening—within 7–11 mg/m^3. At concentration of 225 mg/m^3 there comes the olfactory center paralysis, and in limits—150–1500 mg/m^3 are observed irritation of mucous membranes of a pharynx, metal taste in a mouth, fatigue, a headache and nausea. At concentration of 1500 mg/m^3 and above there can occur almost instant death because of the respiratory center paralysis.

From among products of natural gas burning carbon oxide reduces consumption of oxygen by fabrics as a result of connection of this substance with hemoglobin. At persons in a coma or dying of sharp intoxication, that is as a result of single or short-term influence of substance, in blood usually not less than 50 % of the carbon oxide connected to hemoglobin though cases of death of people at its smaller contents meet.

Inhalation of air with the maintenance of 0.25–1.0 % of other product of burning of natural gas—carbon dioxide, gaseous substance with sourish taste and smell, is followed by change of normal function of breath and blood circulation, 2.5–5.0 % of carbon dioxide cause a headache, irritation of the top airways, increase of heartbeat and other symptoms. At 7 % of carbon dioxide and above there are a perspiration and noise in ears, vomiting, sight violation, etc. People maintain concentration in 10 % of carbon dioxide no more than 0.5 min. At 20 % of carbon dioxide there occurs the death from respiratory standstill in some seconds, and usually without spasms.

From nitrogen oxides its dioxide represents gas of brown-red color with a specific smell. At concentration of nitrogen oxides in air in 120 mg/m^3 (in terms of nitrogen dioxide) there is an irritation in a pharynx, at 200 mg/m^3—cough. At short-term influence 200–300 mg/m^3 are considered dangerous, hours-long influence concentrations not higher than 70 mg/m^3 are endured.

Sulfur dioxide, gaseous substance with a pungent suffocating smell, possesses an irritant action, which is shown in primary defeat of the bronco-pulmonary device as at sharp, and chronic intoxication, that is as a result of long influence of substance. At slight intoxication by sulfur dioxide (0.001 % on volume) appears the irritation of mainly top airways and eyes with developing of irritation and feeling of dryness in a throat, cough, epiphora and other symptoms. At the heavy intoxication connected with big concentration influence of dioxide of sulfur (0.04–0.05 % on volume) there comes asthma within several minutes. It is considered that sulfur dioxide causes pretumoral changes in pulmonary fabric, creating thereby conditions for manifestation of cancerogenic effect of such substance as benz(a)pyrene.

Benz(a)pyrene in the vaporous and absorbed on particles of soot and dust state gets on the air environment and is found in rather high concentration at long distances (5–10 km) from a pollution source (Lebedeva 2010). Benz(a)pyrene is the most typical cancerogenic substance and can come to a human body in various ways, including through respiratory organs, causing irreversible changes in living cell up to formation of malignant tumors.

Control of the content of natural gas and products of its burning in air of a working zone and the occupied places can be carried out according to hygienic standards in the form of the maximum permissible concentration (MPC) of these substances (Table 1) (Andreev et al. 2011). In particular under MPC of substance in air of a working zone is meant as that concentration, which during all working experience shouldn't cause a disease or a deviation in a state of health. Maximum single of substance MPC is that concentration in air of the occupied places, which at inhalation within 30 min shouldn't cause reflex reactions in a human body. And finally, average daily of substance MPC is that concentration in air of also occupied places, which shouldn't make on the person negative impact at uncertain a long (years) inhalation.

Table 1 Maximum permissible concentration (MPC) of substances in air

Substance	MPC	Value, mg/m^3, *mkg/m^3
Natural gas	In working zone for alkanes (methane-dekane) in terms of carbon	300
	Maximum single, the same	100
	Average daily (on pentane), the same	25
	Maximum single (for butane)	200
Hydrogen sulphide	In working zone	10
	In the same place, in mix with hydrocarbons (methane-pentane)	3
	The maximum single	0.008
Carbon oxide	In working zone, during the working day	20
	In the same place, within 60 min	50
	In the same place, within 30 min	100
	In the same place, within 15 min	200
	The maximum single	5
	The average daily	3
Nitrogen oxides	In working zone, for mixes of nitrogen oxides	5
	Maximum single, for nitrogen oxide	0.4
	Average daily, for nitrogen oxide	0.06
	In working zone, for nitrogen dioxide	2
	Maximum single, for nitrogen dioxide	0.085
	Average daily, for nitrogen dioxide	0.04
Sulfur dioxide	In working zone	10
	The maximum single	0.5
	The average daily	0.05
Benz(a)pyrene	In working zone	0.15*
	The average daily	0.001*

4 Development of Methodological Approaches

The purpose of this section is a comprehensive objective assessment of the biological, biogeochemical and geochemical parameters of ecosystems, as input for various modeling, for developing sound criteria for the evaluation of geoecological situation in the areas of influence of objects of “Gazprom Dobycha Yamburg” LLC.

Given the complex nature of the work, the following tasks were set on comprehensive assessment of atmotechnogenic pollution on different links in the biogeochemical cycle:

– chemical composition of natural waters with emphasis on eutrophic and acid substances and heavy metals;
– chemical composition of bottom sediments with emphasis on heavy metals and phosphorus;

– accumulation in the soil of heavy metals and their relationship with chemical soil properties;
– content of heavy metals in the indicator species (*Alectoria ochroleuca* and *Betula nana*);
– pace of growth and the concentration of nitrogen in wood of Siberian larch (tree-ring analysis);
– biodiversity of plants, changing plant communities;
– biodiversity of soil biota on the example of oribatid mites.

Given the task, it was necessary to carry out an indicator of enough "subtle" changes in the level of atmotechnogenic load on the studied ecosystem components and their chemical composition. Using as a criterion of contamination of territory by the maximum permissible concentration is not sufficient, because this path analysis allows us to estimate only a dramatic change in the environmental situation. It was therefore proposed an integrated load index of atmotechnogenic pollutants per unit area in ecosystems exposed to emissions from the gas industry. Short name is the index of the load of pollutants, designation—Ip (Bashkin et al. 2012). To calculate the Ip you first calculate the wind speed K_{ws1} depending on the direction of wind and proportional to wind speed, expressed in % (PR in the preparation of wind rose) (Table 2).

Table 3 shows the calculated K_{ws1} for the Taz Peninsula on the three weather stations.

Next, calculate the coefficients of the wind speed K_{ws}, in fact, a "reverse" ratio K_{ws1} and rate of deposition of pollutants K_{dp1} from the equation of linear regression based on the data dependences of total nitrogen deposition near a point source NO_x emission from the direction of the wind.

Table 2 Direction and the wind speed expressed in percentage and units (K_{ws1}) in New Port, Yamburg and Tazowsky weather stations

Wind direction (from the wind)	Wind speed, %			The coefficient wind speed (K_{ws1})			The wind direction from the unit (where the wind blows)
	New Port	Yamburg	Tazowsky	New Port	Yamburg	Tazowsky	
North	22.18	17.86	14.23	1.15	0.93	0.74	South
North-East	5.57	12.10	7.55	0.29	0.63	0.39	South-West
East	7.79	7.99	9.04	0.40	0.42	0.47	West
South-East	9.49	11.23	18.18	0.49	0.58	0.95	North-West
South	17.34	11.89	11.96	0.90	0.62	0.62	North
South-West	7.85	11.72	11.20	0.41	0.61	0.58	North-East
West	14.43	14.74	16.09	0.75	0.77	0.84	East
North-West	15.35	12.47	11.75	0.80	0.65	0.61	South-East

Note. Correction factors K_{ws1} calculated based on the average of the sum of the coefficients of the K_{ws} (equal 5.20) for the three weather stations

Table 3 Coefficients of wind speed (K_{ws}) and deposition of pollutants (K_{pd1}) depending on the direction and speed of wind in New Port, Yamburg and Tazowsky weather stations

The wind direction from the unit (where the wind blows)	The coefficient wind speed (K_{ws1})			The coefficient of deposition of pollutants (K_{dp1})		
	New Port	Yamburg	Tazowsky	New Port	Yamburg	Tazowsky
South	1.15	0.93	0.74	0.93	0.75	0.60
South-West	0.29	0.63	0.39	0.24	0.51	0.32
West	0.40	0.42	0.47	0.33	0.34	0.38
North-West	0.49	0.58	0.95	0.40	0.47	0.76
North	0.90	0.62	0.62	0.73	0.50	0.50
North-East	0.41	0.61	0.58	0.33	0.49	0.47
East	0.75	0.77	0.84	0.61	0.62	0.68
South-East	0.80	0.65	0.61	0.65	0.52	0.49

Note. K_{ws}—coefficient wind speed "reverse" ratio K_{ws1}. K_{dp1} calculated by the regression equation $Y = A + B \cdot X$, where $A = 0.003$ and $B = 0.805$, X—factor, obtained by bringing the maximum values of K_{ws} to 1.00 and proportional to the corresponding terms of other values K_{ws}. The equation is obtained by linear regression analysis (correlation coefficient of the equation is equal to 0.59) of data according to the total nitrogen deposition near a point source NO_x emission from the direction of the wind

Table 4 Coefficients deposition of pollutants (K_{pd2}) depending on the direction and speed of wind in New Port, Yamburg and Tazowsky weather stations

The wind direction from the unit (where the wind blows)	Degrees, range		The coefficient of deposition of pollutants (K_{dp2})			
	From	To	New Port	Yamburg	Tazowsky	Mean
South	157.5	202.5	1.00	1.00	0.79	0.93
South-West	202.5	247.5	0.25	0.68	0.42	0.45
West	247.5	292.5	0.35	0.45	0.50	0.44
North-West	292.5	337.5	0.43	0.63	1.01	0.69
North	337.5	22.5	0.78	0.67	0.66	0.70
North-East	22.5	67.5	0.36	0.66	0.62	0.55
East	67.5	112.5	0.65	0.83	0.89	0.79
South-East	112.5	157.5	0.69	0.70	0.65	0.68

Note. K_{dp2} calculated when you cast a maximum value K_{dp1} to 1.00 and proportional to the corresponding terms of other values K_{dp1}

The coefficient of deposition of pollutants K_{dp} is calculated when you cast a maximum value K_{dp1} to 1.00 and proportional to the corresponding terms of other values K_{dp1} (Table 4).

On the basis of general ideas about the form of the regression equations describing the dependence of the size of the atmospheric deposition of pollutants from the distance from the pollutant source (Barcan et al. 1998; Gritsenko et al. 2009; Zvereva and Kozlov 2011), the dependence of nitrogen deposition on the distance from the source of emission of NO_x directly in the impacted zone of objects of "Gazprom Dobycha Yamburg" LLC and the effective distance of a significant impact on the chemical nature of the pollutants on natural objects (Cicek and Koparal 2004) was obtained by a regression equation $P = A \cdot Exp\ (B \cdot X + C \cdot X^2)$, where X is the distance from the source of atmospheric pollutants, P—quantity of pollutant per unit area, A, B and C—coefficients of the regression equation are equal to 1835.45, −0.37347 and 0.0038632, respectively (Fig. 3). The determination coefficient for obtained equations is valid and equal to 0.87 and the correlation coefficient is 0.93. The maximum effective distance of influence of a source of atmospheric pollution adopted 15 km at similar to unit-2 the amount of emissions of pollutants and time impacts on surrounding ecosystems. To formalize the calculation of the notional amount of the drop down pollutants was converted into a coefficient K_{dist} equal to $P_i \cdot 1.00/P_{max}$, calculated and its dependence on the distance from the pollution source, the regression equation of the same form: $K_{dist} = a \cdot Exp\ (b \cdot X + c \cdot X^2)$ (Fig. 4). The coefficients of the regression equation are: $a = 1.14747$, $b = -0.59832$, $c = 0.016861$.

The load index of pollutants is calculated by multiplying the K_{dis} and K_{dp}. If the object under study is in the range of more than one source of atmotechnogenic pollution load indices of pollutants are calculated separately for each source of pollution and then summed.

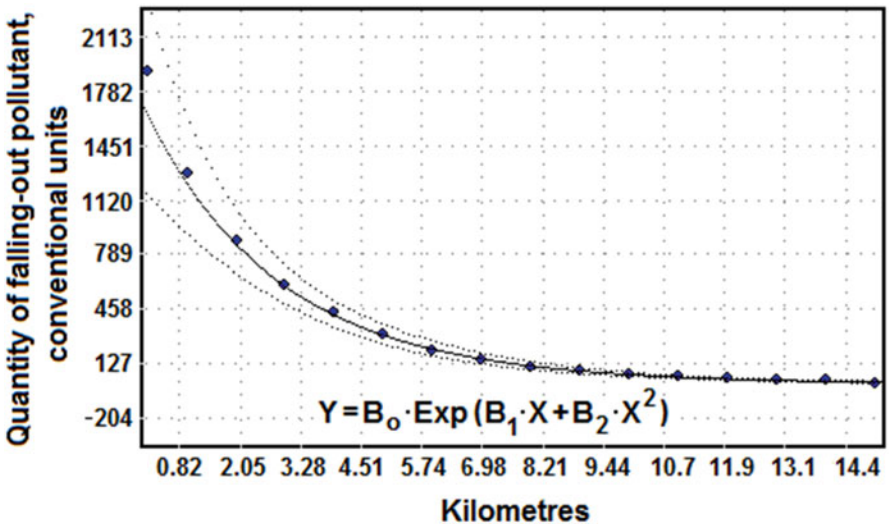


Fig. 3 Equation of nonlinear regression describing the size dependence of deposition of pollutants (P) (y-axis) against the distance (in kilometers) from a point source pollutant emission (x-axis)

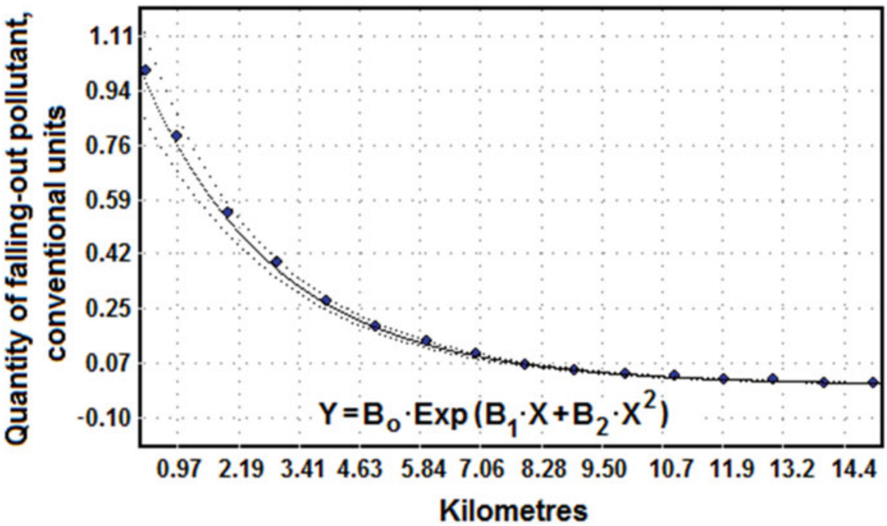


Fig. 4 Nonlinear regression equation describing the dependence of the coefficient of deposition of pollutants (K_{dp}) (y-axis) against the distance (in kilometers) from a point source pollutant emission (x-axis)

5 Retrospective Analyses of Pollutant Loading

Emissions of pollutants in production facilities of "Gazprom Dobycha Yamburg" LLC are connected (1) with the technology and related processes and (2) the combustion of fuel to generate electricity and heat (Bashkin and Galiulin 2013; Galiulin et al. 2015). The total number of sources of air pollution is about 2000, including about 1700—organized. Not taking into account methane emissions, among atmospheric pollutants the main emissions are carbon monoxide and nitrogen oxides, hydrocarbons (excluding methane), particulate matter and sulfur dioxide. The ratio of pollutants in the emissions of two groups of different sources is shown in Fig. 4.

Not considering the emissions of methane, the main volumes of atmospheric emissions of pollutants are oxides of carbon and nitrogen. Emissions of solid particulates, sulfur dioxide and hydrocarbons are characterized by a low contribution to the total emission of pollutants.

For most process plants operating in the system of "Gazprom" JSC, the main pollutants of the 1st hazard category, power output, and volume of the annual gross emissions are oxides of nitrogen (Gritsenko et al. 2009). Dynamics of emissions in production facilities of "Gazprom Dobycha Yamburg" LLC for the period 2004–2008 in terms of NO_2 is presented in Fig. 5. As can be seen, the total level of emissions of nitrogen oxides from the combustion of fuel to generate electricity and thermal energy in the period under review remained virtually unchanged, averaging about 2000 tons/year. Emissions of nitrogen oxides associated with technological and related processes, since 2005 was on average three times higher than the

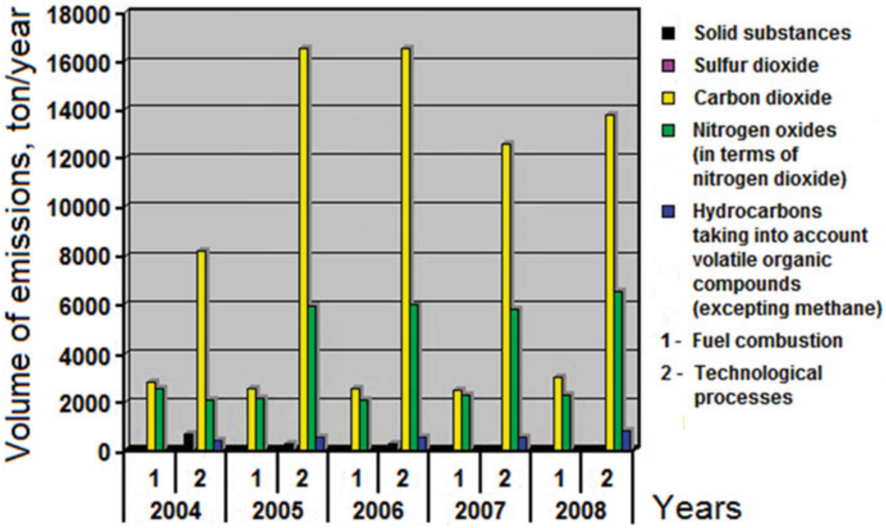


Fig. 5 The retrospective dynamics of the total atmospheric emissions of pollutants (ton/year) of production facilities of "Gazprom Dobycha Yamburg" LLC for 2004–2008

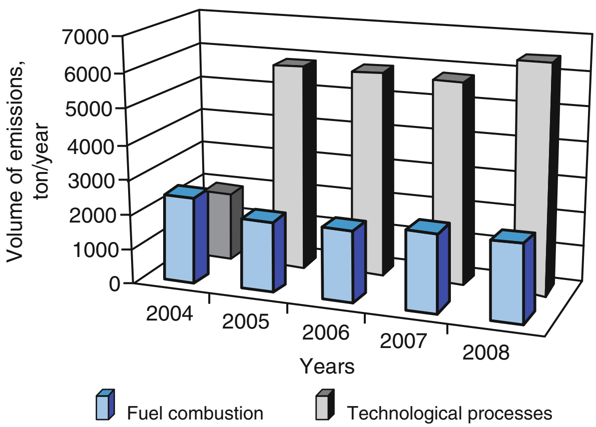


Fig. 6 Evolution of the total atmospheric emissions of nitrogen oxides (tons/year) of production facilities of "Gazprom Dobycha Yamburg" LLC for 2004–2008

combustion of fuel for own needs. Thus, the priority pollutants for the zone of influence of the production facilities of "Gazprom Dobycha Yamburg" LLC should be regarded as oxides of nitrogen.

Analysis of the conditions of exposure and routes of exposure to anthropogenic air pollutants can cause direct and indirect exposure of recipients. In the first case it is inhalation or contact-surface effects of pollutants on living organisms as a result of excessive concentrations of toxicants. The second impact, as a rule, is more complex and involves redistribution of contaminants in environmental compartments after their deposition on the underlying surface with subsequent migration along the trophic chains. Thus, there is a formation of several exposure routes. The general atmospheric circulation of air masses in the Northern part of Western Siberia determines the direction and intensity of migration of pollutants from emission sources to the deposition area of their transformation products in terrestrial and freshwater ecosystems. According to available data in the literature, direction and speed of atmospheric flows in the area are differentiated by the seasons. The autumn-winter-spring period is characterized by West (latitudinal) direction of air masses movement, alternating in the summer in the South-South-West (close to meridional). The most intensive transfer of moisture and pollutants occurs in the atmosphere in spring. This specificity determines the square of the dispersion and deposition of anthropogenic compounds in components of the environment in the impacted zone of objects of “Gazprom Dobycha Yamburg” LLC. Considering the emission of pollutants is relatively uniform throughout the year, we can assume that the spatial pattern of the zone of exposure consists of two components. The most intense total impact occurs in a westerly direction from the emission sources. However, most of the pollutants received by the environment in autumn-winter-spring period, is accumulated in the snow cover, with “shielding” effect. With the spring snowmelt runoff accumulated anthropogenic compounds can be redistributed between geochemically related ecosystems, including inflow to numerous water bodies, forming in them the "peak" concentrations of pollutants. In the summer, which is characterized by a predominantly southern direction of transport of pollutants, there is a relatively even flow of anthropogenic compounds directly on the underlying surface, which can lead to the formation of permanent increased “soil background” of pollutants. Depending on the nature and levels of pollutants, environmental effects of emissions of “Gazprom Dobycha Yamburg” LLC on natural ecosystems and different groups of recipients can be differentiated.

6 Conclusions

Considering the impacts of gas industry on natural ecosystems and assessing the factors of geo-environmental risks of pollutant emission we must accounting for the following routes of exposure:

– emission sources—redistribution and transformation of pollutants in the air—the formation of stray fields of pollutants with different levels of concentrations in the atmospheric surface layer;
– emission sources—redistribution and transformation of pollutants in the air—deposition of pollutants on the underlying surface—depositing in the upper layer of soil;
– emission sources—redistribution and transformation of pollutants in the air—deposition of pollutants on the underlying surface—removal of pollutants from the upper layer of soils with soil and groundwater runoff to aquatic ecosystems (wetlands and riverine).

References

Andreev, O. P., Bashkin, V. N., Galiulin, R. V., Arabsky, A. K., & Makliuk, O. V. (2011). *Solution of geo-environmental risks problem in the gas industry. Survey information*. Moscow: Gazprom VNIIGAZ Publishing House. 78pp.

Barcan, V. S., Kovnatsky, E. F., & Smetannikova, M. S. (1998). Absorption of heavy metals in wild berries and edible mushrooms in the areas affected by smelter emissions. *Water, Air and Soil Pollution, 103*, 173–195.

Bargagli, R. (2005). *Antarctic ecosystems: Environmental contamination, climate change, and human impact*. Berlin, London: Springer Publishers. 395pp.

Bashkin, V. (2002). *Modern biogeochemistry*. Dordrecht; London; Boston: Kluwer Academic Publishers. 572pp.

Bashkin, V. N. (2006). *Modern biogeochemistry: Environmental risk assessment* (2nd ed.). Berlin, London: Springer Publishers. 444pp.

Bashkin, V. N., & Priputina, I. V. (2010). *Management of environmental risks at emission of pollutants*. Moscow: Gazprom VNIIGAZ Publishing House. 189pp.

Bashkin, V. N., Arno, A. B., Arabsky, A. K., Barsukov, P. A., Priputina, I. V., & Galiulin, R. V. (2012). *Retrospective and forecast of geoecological situation on gas-condensate fields of the far north*. Moscow: Gazprom VNIIGAZ Publishing House. 280pp.

Bashkin, V. N., & Galiulin, R. V. (2013). Climate change and forecast of natural gas consumption. *Gas Industry, 1*, 58–60.

Bashkin, V. N. (2014). *Biogeochemistry of polar ecosystems in the gas industry impacted zones*. Moscow: Gazprom VNIIGAZ Publishing House. 302pp.

Boev, V. M., & Setko, N. P. (2001). *Sulfurous compounds of natural gas and their action on organism*. Moscow: Meditsina Publishing House. 216pp.

Bret-Harte, M. S., Shaver, G. R., & Chapin, F. S. (2002). Primary and secondary growth in arctic shrubs: Implications for community response to environmental change. *Journal of Ecology, 90*, 251–267.

Cicek, A., & Koparal, A. S. (2004). Accumulation of sulfur and heavy metals in soil and tree leaves sampled from the surroundings of Tuncbilek Thermal Power Plant. *Chemosphere, 57*(8), 1031–1036.

Demidova, O. A. (2007). *Development of methods of ecosystem risks assessment in zones of impact of emissions of the gas industry objects*. The thesis for candidate's degree of technical sciences. Moscow: Gazprom VNIIGAZ Publishing House, 172pp.

Deslippe, J. R., Egger, K. N., & Henry, G. H. R. (2005). Impacts of warming and fertilization on nitrogen fixing microbial communities in the Canadian High Arctic. *FEMS Microbiology Ecology, 53*, 41–50.

France, R., & Coquery, M. (1996). Lead concentrations in lichens from the Canadian High Arctic in relation to the latitudinal pollution gradient. *Water, Air and Soil Pollution, 90*, 469–474.

Galiulin, R. V., Bashkin, V. N., & Galiulina, R. A. (2015). Prospects of development and interaction of alternative power engineering and gas industry. *Magazine of Oil and Gas Construction, 2*, 47–52.

Gorham, E. (1991). Northern peatlands—Role in the carbon cycle and probable responses to climatic warming. *Ecological Applications, 1*, 182–195.

Gough, L., Wookey, P. A., & Shaver, G. R. (2002). Dry heath arctic tundra responses to long-term nutrient and light manipulation. *Arctic, Antarctic, and Alpine Research, 34*(2), 211–218.

Gritsenko, A. I., Maksimov, V. M., Samsonov, R. O., & Akopova, G. S. (2009). *Ecology: Oil and gas*. Moscow: IKTS «Akademkniga» Publishing House. 680pp.

Hobbie, S. E., & Chapin, F. S. (1996). Winter regulation of tundra litter carbon and nitrogen dynamics. *Biogeochemistry, 35*, 327–338.

Jonasson, S., Michelsen, A., Schmidt, I. K., & Nielsen, E. V. (1999). Responses in microbes and plants to changed temperature, nutrient, and light regimes in the arctic. *Ecology, 80*(6), 1828–1843.

Lebedeva, E. A. (2010). *Protection of air basin from harmful technological and ventilating emissions*. Nizhny Novgorod: NNGASU Publishing House. 196pp.

Mack, M. C., Schuur, E. A. G., Bret-Harte, M. S., Shaver, G. R., & Chapin, F. S., III. (2004). Ecosystem carbon storage in arctic tundra reduced by long-term nutrient fertilization. *Nature, 431*, 440–443.

McKane, R. B., Rastetter, E. B., Shaver, G. R., Nadelhoffer, K. J., Giblin, A. E., Laundre, J. A., et al. (1997). Climatic effects on tundra carbon storage inferred from experimental data and a model. *Ecology, 78*(4), 1170–1187.

Moskovchenko, D. V. (2010). *Geochemistry of landscapes of the West Siberian plain north: The structurally functional organization of geosystems substance and problems of ecodiagnostics.* Abstract of the thesis for doctor's degree of geographical sciences. Sankt-Petersburg: Sankt-Petersburg State University Press, 33pp.

Nemergut, D. R., Townsend, A. R., Sattin, S. R., Freeman, K. R., Fierer, N., Neff, J. C., et al. (2008). The effects of chronic nitrogen fertilization on alpine tundra soil microbial communities: Implications for carbon and nitrogen cycling. *Environmental Microbiology, 10*, 3093–3105.

Nieboer, E., Richardson, D. R., & Tomassini, F. D. (1978). Mineral uptake and release by lichens: An overview. *Bryologist, 81*(2), 226–246.

Safonov, V. S., Volkov, A. N., Kovalev, S. A., Lesnykh, V. V., Petrulevich, A. A., & Radaev, N. N. (2008). Categorization of «Gazprom» JSC objects on degree of potential danger: Theory and practice. In *Industrial and ecological safety of the gas industry objects* (pp. 151–164). Moscow: Gazprom VNIIGAZ Publishing House.

Semenov, M. Y. (2002). *Resistance of ecosystems of Asian part of Russia to acid deposition*. Novosibirsk: Nauka Publishing House. 152pp.

Shaver, R., Phoenix, G. K., Jones, D. G., Jonasson, S., Chapin, F. S., Molau, U., et al. (2001). Global change and arctic ecosystems: Is lichen decline a function of increases in vascular plant biomass? *Journal of Ecology, 89*, 984–994.

Stapleton, L. M., Crout, N. M. J., Sawstram, C., Marshall, W. A., Poulton, P. R., Tye, A. M., et al. (2005). Microbial carbon dynamics in nitrogen amended arctic tundra soil: measurement and model testing. *Soil Biology and Biochemistry, 37*, 2088–2098.

Sturm, M., Racine, C., & Tape, K. (2001). Climate change—Increasing shrub abundance in the Arctic. *Nature, 411*, 546–547.

Zvereva, E. L., & Kozlov, M. V. (2011). Impacts of industrial polluters on bryophytes: A meta-analysis of observational studies. *Water, Air, and Soil Pollution, 218*(1–4), 573–586.

Modern Biogeochemical Cycling in Gas Industry Impacted Areas

Vladimir N. Bashkin, Pavel A. Barsukov, and Anatoly K. Arabsky

Abstract On a basis of field monitoring of modern biogeochemical cycling in gas industry impacted areas was shown the absence of any strong remarkable alterations in studied biogeochemical system: surface waters-bottom sediments-plants. In the contrary, the paper results indicate very significant influence on the productivity of lichens and, in general, on the functioning of tundra ecosystems.

Keywords Biogeochemical cycling • Gas industry impacted zone • Ecosystem functioning • Tundra ecosystems • Environmental pollution

1 Introduction

The study area is located in the impacted zone of LLC "Gazprom Dobycha Yamburg" and is found mostly on the Taz Peninsula in the Taz landscape province of the West Siberian plain, and from the point of view of biogeographical zonation it is the south tundra subzone and forest-tundra zone.

Most of the surface of the Taz landscape province is composed of clayey-sandy rocks of Upper Quaternary boreal transgression and alluvial sediments. Almost everywhere it is dominated by flat, strongly swampy plain rising above the sea level no more than

V.N. Bashkin (✉)
Institute of Physicochemical and Biological Problems of Soil Science of Russian Academy of Sciences, Pushchino, Moscow Region 142290, Russian Federation

Institute of Natural Gases and Gas Technologies—Gazprom VNIIGAZ LLC, Razvilka, Moscow Region 142719, Russian Federation
e-mail: bashkin@issp.serpukhov.su

P.A. Barsukov
Institute of Soil Science and Agrochemistry of Siberian Branch of Russian Academy of Sciences, Novosibirsk 630099, Russian Federation

A.K. Arabsky
Gazprom Dobycha Yamburg LLC, Novy Urengoy, Yamalo-Nenets Autonomous District 629300, Russian Federation

V.N. Bashkin (ed.), *Biogeochemical Technologies for Managing Pollution in Polar Ecosystems*, Environmental Pollution 26, DOI 10.1007/978-3-319-41805-6_4

50 m. Only near the western margin of the province the northern stretches of the Nenets spurs of low hills (highest point to 88 m) are located. The surface is weakly dissected by a network of mainly short and shallow river valleys. Terraces on their slopes are usually absent. Many inter-spaces are often not completely mastered by modern fluvial erosion and not drained by rivers, in connection with which there are many closed lake basins. If river erosion happens in the tundra, it is only during the short warm season. Even in June, after the snow cover disappears, the processes of erosion at first time are small, because the soil is still frozen by permafrost. Processes of solifluction, leveling uneven terrain, accompany the horizon thawing of seasonal frost penetration in areas with clay and loamy soils. And here are formed such cryogenic form of microrelief as pingos (hills), thermokarst depressions, peat mounds, spot medallions, and polygons.

All the rivers have meandering channel. Melted snow waters and summer rain feed them. Tundra rivers often pass through a chain of lakes, which are located in valleys and significantly regulate flow. Many lakes are in river interfluves, where they fill glacial or thermokarst depression.

Snow cover in open areas is from early October to mid-June; on the slopes of river valleys and in depressions it remains in some places until the beginning of July. Due to the strong winter winds, the snow cover very uneven: often elevated areas are generally deprived of snow during the whole winter, but in depressions and valleys, it accumulates in drifts and coalfaces of considerable power.

A common feature of natural conditions of the Northern part of Western Siberia that determine the formation of landscape-geochemical patterns are widespread permafrost, the slow rate of biological circulation, wet, widespread reductive environment in soils (Perelman and Kasimov 1999; Bashkin and Kasimov 2004). Analysis of the microelement composition of soil-forming rocks, differing in genesis, show that the greatest influence on the content of chemical elements in parent rocks has a particle size distribution. The content of minerals in sandy rocks is 1.3–3 times smaller than in loamy soils. Maximum concentrations of trace elements detected in marine rock species, the minimum—in the lacustrine-alluvial sediments of the southern part of the Taz peninsula. Compared to clarks, loamy rocks are characterized by a reduced content of lead, zinc and strontium. The content of manganese, titanium, chromium in most of the studied rocks close to the world average indicators. In the distribution of manganese, cobalt, and nickel, there are significant spatial differences—both accumulation zones and zones of scattering, characteristic of the sediments of lacustrine-alluvial genesis (Moskovchenko 2010).

The generalized data characterizing the elemental composition of soil of tundra are presented in Table 1.

Table 1 Elemental composition of the soils of tundra of Western Siberia, M ± M (mg/kg)

Territory	Mn	Cu	Ni	Zn	Cr
South of Taz peninsula	270 ± 51	9.4 ± 1.6	13.3 ± 3.1	22 ± 7.0	46 ± 8.1
Soil Clark	850	20	40	50	200
Territory	Sr	Co	Pb	Cd	Ba
South of Taz peninsula	9.5 ± 0.6	6.3 ± 0.6	7.7 ± 1.3	0.4 ± 0.05	276 ± 30
Soil clark	300	10	10	0.5	500

Table 2 Regional background levels of heavy metals in soils of northern part of West Siberia, mg/kg

Territory	Mn	Cu	Ni	Zn	Cr	Sr	Co
South of Taz peninsula and Yamal peninsula (Moskovchenko 2010)	370	13	26	25	31	32	7.4
North of West Siberia (Sorokina et al. 2001)	402	32.3	9.6	41.5	56	44	6.2
Urengoy tundra (Arestova 2003)	82	38	10	70	20	50	9
Territory	Pb	Cd	Ba	V	Ti	Zr	
South of Taz peninsula and Yamal peninsula (Moskovchenko 2010)	6.1	0.41	578	87	4200	120	
North of West Siberia (Sorokina et al. 2001)	13.5	–	125	98	4873	132	
Urengoy tundra (Arestova 2003)	10	0.5	100	30	1400	130	

The spatial differences in trace element composition of soils are largely determined by lithological factors. Thus, the prevalence of sandy alluvial-marine sediments in the northeastern part of Yamal peninsula leads to poor composition of the soil compared to soils of western Yamal. When comparing the composition of soils of the western and eastern parts of the Yamal Peninsula it is obvious that in the West the soils have higher concentrations of most elements except nickel and chromium. A comparison with the data from other sites (Sorokina et al. 2001; Arestova 2003) shows the low content of copper, lead and zinc in soils of Yamal and Taz peninsulas. The content of barium and nickel, on the contrary, is increased, although in most cases does not exceed clark of soils (Table 2).

The functioning and resilience of natural systems during the input of anthropogenic fluxes depend on the degree of sustainability and activity of organic matter, and hence the stability of the existing biogeochemical processes (Moskovchenko 2010; Bashkin et al. 2012). Therefore it seems very important the understanding geochemical and biogeochemical nature of gley and detritogenegis processes, playing a major role in the formation of the soil cover of the West Siberian tundra. It is determined that in the ash composition of plants, which are forming the peats, the predominant elements are phosphorus and manganese, in sum exceed 1 %. Compared to the average content of trace elements in the ash of terrestrial plants, the plants of subarctic tundra of the Yamal have the elevated concentrations of Mn, Ba, Co, and Ni. Below clark is the content of V, Cr, Mo. The coefficients of biological accumulation showed that the maximum values are characteristic for the elements related to strong cations (Ba, Mn, Sr, Zn, Pb) in the given landscape-geochemical conditions. It is characteristic that the absolute concentration and the total intensity of biological accumulation in plants of the subordinate hydromorphic geosystems lower than in the automorphic geosystem of the flat interfluves. The maximum accumulation of trace elements is characteristic for edificators and dominants of zonal tundra.

Shrubs (dwarf birch, willow PPE) are characterized by very intense accumulation of zinc, exceeding an order of magnitude the accumulation of other living organisms. Lichens are distinguished by the number of stacked Ti, Pb, V and Ga. Features of accumulation of chemical elements by plants largely determine the composition of surface soil horizons. In organogenic horizons of tundra peaty gley soils, as in plant material, there is a high content of biogenic elements—phosphorus, manganese and zinc. Comparison of microelement composition of soils in different landscape conditions, indicates that the content of elements, in particular elements of biological accumulation, is decreased with increasing hydromorphism. For example, in wetland soils manganese from elements of biological accumulation becomes an element of biological capture, its content is less than in mineral rock ($Cu < 1$).

Geochemical features of soils, gley genesis role-defined, can be seen on the example of migration and accumulation of iron and manganese—elements that largely determine the specificity of landscape-geochemical conditions. With the increasing gleyed soil profile the pH of aqueous and salt extracts increases, as well as the mobility of iron and manganese, leading to their removal from gley horizons. The intensity of removal is maximal not in the congestion regime, peculiar to the swamps, but in stagnant-leaching regime of flat watersheds. The lowest iron content was observed in marsh-tundra and rough-humus gley soils; the maximum concentration is characteristic for alluvial soils where iron is deposited on the oxidation barrier (Moskovchenko 2010).

As already noted above, the functioning of natural systems during the invasion of anthropogenic fluxes depend on the organic matter functioning, and hence the latter determines the stability of the existing biogeochemical processes (Bashkin 2006; Moskovchenko 2010; Bashkin et al. 2012). The tundra ecosystems (as well as all of the high-latitude and high-altitude ecosystems in general) are the most vulnerable to all kinds of anthropogenic and conventionally natural (climate change) impacts.

Thus, the above hydrothermal, vegetation and soil parameters emphasize the belonging of the study territory to tundra ecosystems with depressive type of biogeochemical cycle (Bashkin, Natural biogeochemical cycling in polar ecosystems).

2 Parameterization of Biogeochemical Cycling in Gas Industry Impacted Ecosystems

2.1 Influence of Atmospheric Pollutants on Biogeochemical Indices of Surface Waters

To study the effect of atmospheric pollutants on the chemical composition of surface waters 17 lakes were selected, located on different distance from the pollutant emission sources (Table 3). The load indices of pollutants (Ip) are calculated in accordance with (Bashkin, Galiulin, Barsukov, Arabsky, Gas industry impacts on natural ecosystems).

In the analysis of surface water, attention was paid to acid (sulfur and nitrogen) and eutrophic (phosphorus and nitrogen) compounds. In all water samples, these figures do not exceed MPC. The value of water pH varies from 5.4–6.7 (Table 4).

Table 3 Registry of samples of surface water and bottom sediments on key sites near different sources of pollution on the territory of LLC "Gazprom Dobycha Yamburg" and load indices of pollutants (Ip)

	Coefficient of pollutant deposition (Kdp) near monitoring sites				Ip	Ip total
Sampling plot symbol	New Port	Yamburg	Tazowsky	Coefficient Kdist	Mean	Mean
L-1	0.30	0.56	0.46	0.005	0	0.2
L-2	1.00	1.00	0.79	0.617	57	76
	0.50	0.74	0.75	0.024	2	
	0.39	0.54	0.75	0.016	1	
	0.67	0.76	0.77	0.206	15	
	0.36	0.66	0.62	0.020	1	
L-3	0.85	0.85	0.72	0.672	54	75
	0.85	0.85	0.72	0.022	2	
	0.39	0.54	0.75	0.018	1	
	0.67	0.76	0.77	0.225	17	
	0.36	0.66	0.62	0.024	1	
L-4	0.36	0.66	0.62	0.890	48	63
	0.85	0.85	0.72	0.013	1	
	0.39	0.54	0.75	0.014	1	
	0.69	0.70	0.65	0.153	10	
	0.36	0.66	0.62	0.033	2	
L-5	0.43	0.63	1.00	0.798	55	66
	0.85	0.85	0.72	0.012	1	
	0.39	0.54	0.75	0.010	1	
	0.69	0.70	0.65	0.111	8	
	0.50	0.74	0.75	0.025	2	
L-6	0.61	0.65	0.83	0.545	38	46

(continued)

Table 3 (continued)

Sampling plot symbol	Coefficient of pollutant deposition (Kdp) near monitoring sites			Coefficient Kdist	Ip	Ip total
	New Port	Yamburg	Tazowsky		Mean	Mean
	0.69	0.70	0.65	0.087	6	
	0.50	0.74	0.75	0.031	2	
L-7	0.39	0.54	0.75	0.221	12	16
	0.67	0.76	0.77	0.036	3	
	0.50	0.74	0.75	0.013	1	
L-8	0.39	0.54	0.75	0.831	47	70
	0.30	0.56	0.46	0.021	1	
	0.36	0.66	0.62	0.024	1	
	0.61	0.65	0.83	0.184	13	
	0.67	0.76	0.77	0.091	7	
	0.61	0.65	0.83	0.021	1	
L-9	0.36	0.66	0.62	0.105	6	20
	0.30	0.56	0.46	0.192	8	
	0.63	0.84	0.60	0.048	3	
	0.35	0.45	0.50	0.016	1	
	0.43	0.63	1.00	0.024	2	
L-10	0.69	0.70	0.65	0.669	46	46
	0.25	0.68	0.42	0.019	1	
L-11	0.85	0.85	0.72	0.472	38	39

	0.25	0.68	0.42	0.027	1	
L-12	0.85	0.85	0.72	0.975	78	79
	0.25	0.68	0.42	0.018	1	
L-13	0.36	0.66	0.62	0.930	51	51
	0.25	0.68	0.42	0.015	1	
L-14	0.35	0.45	0.50	0.757	33	35
	0.25	0.68	0.42	0.022	1	
	0.39	0.54	0.75	0.011	1	
L-15	0.39	0.54	0.75	0.013	1	27
	0.30	0.56	0.46	0.571	25	
	0.25	0.68	0.42	0.027	1	
L-16	0.85	0.85	0.72	0.016	1.3	2.7
	0.67	0.76	0.77	0.019	1.4	
L-17	0.85	0.85	0.72	0.007	1	1
	0.67	0.76	0.77	0.006	0	

Table 4 Hydrochemical indexes of surface waters in the gas industry impacted areas

Sampling plot symbol	Ip	Dry residue mg/l	Water pH	Conductivity µS/cm^2	N-NO_3^- mg/l	N-NH_4^+ mg/l	P-PO_4^{2-} mg/l	S-SO_4^{2-} mg/l	Oil products mg/l	Phenols mg/l	Surfactants mg/l
L-1	0.2	31	6.05	23.9	0.50	1.93	0.073	0.43	0.008	0.0001	0.001
L-2	76	170	6.70	59.6	4.54	0.33	0.091	3.50	0.039	0.0007	0.008
L-3	75	74	5.42	40.2	3.68	0.49	0.052	2.28	0.030	0.0002	0.005
L-4	63	212	5.80	52.3	11.91	0.86	0.053	4.24	0.038	0.0001	0.001
L-5	66	53	6.56	37.3	3.53	0.33	0.067	2.09	0.027	0.0001	0.002
L-6	46	320	5.93	49.6	6.35	1.65	0.023	4.03	0.013	0.0001	0.001
L-7	16	23	5.96	15.9	1.96	1.02	0.014	1.12	0.021	0.0001	0.001
L-8	70	88	5.21	22.7	5.37	0.75	0.138	3.22	0.024	0.0002	0.005
L-9	20	238	5.77	26.7	2.04	1.70	0.117	2.38	0.072	0.0001	0.012
L-10	46	60	5.96	37.9	4.02	0.75	0.082	1.48	0.210	0.0001	0.003
L-11	39	367	6.24	107.9	4.35	0.49	0.104	2.83	0.011	0.0001	0.010
L-12	79	718	5.55	57.7	5.70	0.31	0.073	5.75	0.097	0.0015	0.019
L-13	51	93	6.10	17.3	2.32	0.49	0.025	1.70	0.025	0.0001	0.008
L-14	35	200	5.73	17.6	3.24	0.49	0.071	2.78	0.017	0.0001	0.001
L-15	27	100	5.72	15.7	2.74	1.02	0.057	1.96	0.021	0.0001	0.008
L-16	2.7	56	6.26	34.3	4.35	0.75	0.104	1.52	0.022	0.0002	0.012
L-17	1.0	209	5.99	26.9	2.98	0.49	0.114	1.70	0.024	0.0001	0.003
Mean		177	5.94	37.86	4.09	0.82	0.07	2.53	0.0411	0.0002	0.0059
SD		172.5	0.378	23.199	2.497	0.505	0.035	1.314	0.049	0.000	0.005

The content of oil products, phenols and surfactants in waters also not exceed the MCL, and only in the sample of lake l-12 is very close to MPC.

In the same sample received the exceedance for manganese and strontium and the iron content close to the MPC (Table 5). In all other surface water samples for these and other indicators, the exceedance is not detected.

Correlation analysis of different indicators of the chemical composition of the water samples of lakes near the sources of atmospheric pollutants and their comparison with the calculated load index of pollutants allowed to reveal the following regularity: with the increase of load index of atmospheric pollutants insignificantly increases the nitrate content (R = 0.50), sulfate (R = 0.68), iron (R = 0.53) and lithium (R = 0.48), and a significantly reduced content of ammonia nitrogen (R = −0.52).

In regard to other indicators of the chemical properties of surface water significant changes were not revealed.

2.2 *Effects of Atmospheric Pollutants on Biogeochemical Indices of Bottom Sediments*

To study the effect of atmospheric pollutants on the chemical composition of bottom sediments were selected 17 lakes located at different distance from the pollution sources. Samples of the 20 cm surface layer of sediment were collected in 3 replicates at a distance of 5 m from the shoreline. The calculated indices of atmospheric load of pollutants in the places of sampling are presented in Table 6. The second and third repeated samples of sediment were collected, respectively, in 50 m on the left and right of the selection of the first repetition.

In the analysis of bottom sediments the emphasis was on phosphorus as the most important eutrophic element and heavy metals. Comparison of the obtained values of chemical composition of bottom sediments has shown that they lie within the values obtained by other authors in the tundra zone of Western Siberia (Dorozhukova and Yanin 2004). We can just note a little bit more high content of iron and lead in the analyzed samples of bottom sediments compared to those of other authors (Table 7).

Correlation analysis of different indicators of the chemical composition of bottom sediments of lakes near the sources of atmospheric pollutants and their comparison with the calculated index of the load of pollutants allowed to reveal the following regularity: with the increase of load index of atmospheric pollutants insignificantly increases the chromium content (R = 0.56). In regard to other indicators of the chemical properties of bottom sediments significant changes were not revealed.

It should be noted that the chemical composition of the analyzed layer of bottom sediments largely depends on the organic matter content of sediments, which contrastingly differ in silt-sand and sandy sediments. It is not surprising that significant correlation coefficients (both positive and negative) were obtained when comparing the overall content of organic matter of bottom sediments and most other chemical parameters. The same is also true for total phosphorus content in bottom sediments.

Table 5 Metals in surface waters in the gas industry impacted areas

Sampling plot symbol	Water metal content														
	Ca	Mg	K	Na	Fe	Mn	Zn	Cu	Cr	Co	Pb	Ni	Li	Sr	Cd
	mg/l				mkg/l										
L-1	1.02	0.54	0.29	1.04	9.7	2.40	5.33	0.51	1.11	1.11	1.25	1.60	0.23	12.7	0.02
L-2	2.47	1.06	0.31	2.07	153.3	1.67	0.73	1.73	12.00	3.33	1.13	0.40	1.80	1.11	0.02
L-3	0.94	0.42	0.17	1.07	22.7	3.53	1.07	1.67	3.33	3.33	0.67	1.13	0.85	1.11	0.02
L-4	1.93	0.88	0.63	1.46	5.3	2.53	0.33	1.73	3.33	3.33	0.73	0.11	1.53	24.0	0.02
L-5	2.12	1.06	0.31	0.89	93.3	1.13	0.40	1.03	3.33	1.11	0.67	1.73	2.13	32.7	0.02
L-6	2.07	1.22	0.85	1.39	6.5	5.13	0.80	1.00	16.60	3.33	2.13	0.33	2.27	33.3	0.02
L-7	0.48	0.14	0.15	0.56	44.0	1.60	0.60	0.65	12.00	1.11	0.93	0.11	0.27	28.0	0.02
L-8	0.48	0.24	0.22	1.01	3.8	0.67	1.00	1.12	12.67	1.11	2.80	0.11	0.31	11.0	0.02
L-9	0.40	0.20	0.17	0.53	1.11	4.53	0.97	1.58	9.33	1.11	0.97	1.47	0.26	3.3	0.02
L-10	1.90	0.97	1.03	7.76	3.8	53.80	13.53	0.67	1.11	1.11	1.43	0.11	1.27	42.7	0.02
L-11	1.67	0.90	1.08	8.43	15.3	8.87	1.20	1.67	3.33	1.11	1.40	0.56	1.40	8.5	0.02
L-12	10.00	4.00	2.47	211.50	280.0	122.67	1.04	0.67	1.11	1.11	3.13	0.33	10.33	1413.3	0.20
L-13	0.68	0.36	0.18	1.39	11.3	1.53	0.60	1.20	6.00	1.11	1.33	0.93	0.53	1.11	0.02
L-14	0.52	0.26	0.17	1.19	5.1	1.93	0.80	1.00	1.11	3.33	0.80	0.11	0.24	3.3	0.02
L-15	1.52	0.30	0.25	0.77	1.11	1.33	0.52	1.71	1.11	3.33	1.05	0.11	0.39	1.11	0.02
L-16	1.90	0.76	0.25	1.01	5.7	0.85	0.43	0.93	22.00	3.33	3.20	0.93	0.52	30.3	0.02
L-17	1.14	0.64	0.42	0.83	1.11	4.13	0.33	0.64	3.33	1.11	1.13	0.11	0.67	26.0	0.02
Mean	1.84	0.82	0.53	14.29	39.01	12.84	1.75	1.15	6.64	2.03	1.46	0.60	1.47	98.45	0.03
SD	2.209	0.890	0.587	50.875	74.087	30.944	3.247	0.448	6.345	1.127	0.839	0.581	2.386	339.125	0.043

Table 6 Pollutant load index and physico-chemical composition of bottom sediment samples in water bodies in the gas industry impacted areas

Sampling plot index	Ip	Ignition losses	Hygroscopy, %	Total P	Metal content			
					K	Na	Ca	Mg
		%		%	mg/kg			
L-1	0.2	0.65	0.209	0.0055	12085	4235	1498	190
L-2	76	29.18	4.782	0.0512	8652	6406	1581	1498
L-3	75	28.54	4.082	0.0459	8776	7313	1940	1791
L-4	63	7.47	1.134	0.0134	11515	6797	2039	228
L-5	66	12.92	2.377	0.0287	12478	11998	3119	960
L-6	46	1.72	0.488	0.0107	13020	8580	2760	318
L-7	16	4.1	0.597	0.0094	11156	3499	1140	252
L-8	70	0.5	0.125	0.0035	11153	3748	1379	168
L-9	20	0.72	0.16	0.0033	10796	3499	1200	180
L-10	46	1.73	0.219	0.0038	11591	2998	1199	140
L-11	39	54.58	6.816	0.0585	4661	2989	3344	794
L-12	79	3.72	0.473	0.0092	10781	3424	1397	230
L-13	51	1.42	0.233	0.0044	12093	4457	1899	480
L-14	35	0.557	0.189	0.0035	11588	3566	1499	290
L-15	27	1.77	0.224	0.0031	11180	3284	799	105
L-16	3	13.7	2.904	0.0293	11794	12500	2825	692
L-17	1	1.06	0.269	0.0098	9652	2748	959	168
Mean		9.67	1.49	0.0172	10763	5414	1799	499
SD		14.814	2.014	0.018	1966.8	3094.772	775.469	499.271

Table 7 Metal content in bottom sediment samples in water bodies in the gas industry impacted areas

Sampling plot symbol	Metal content										
	Fe	Mn	Zn	Cu	Cd	Pb	Sr	Li	Cr	Co	Ni
	mg/kg										
L-1	4295	92	9.89	2.40	0.499	6.79	56.9	4.19	1.67	4.99	0.90
L-2	27454	200	46.59	16.64	1.331	14.64	19.8	13.64	78.20	3.35	48.09
L-3	26119	209	52.24	14.78	0.687	12.39	24.6	12.99	61.19	7.46	68.06
L-4	7097	159	17.79	5.60	0.033	9.70	54.8	6.00	22.19	5.00	8.20
L-5	15297	238	29.99	11.70	0.033	13.40	60.0	10.60	1.67	8.00	10.90
L-6	7800	178	18.00	5.30	0.033	11.00	77.0	6.10	9.60	3.35	15.50
L-7	3349	81	7.30	2.10	0.033	8.60	46.7	4.00	8.50	1.67	2.80
L-8	3448	106	6.90	2.20	0.033	6.20	55.7	3.40	25.48	1.67	4.30
L-9	4398	161	7.90	2.50	0.033	5.70	53.4	3.90	36.79	5.00	6.70
L-10	2798	107	7.89	1.70	0.360	7.49	42.0	3.30	1.67	5.00	7.49
L-11	12228	207	10.66	6.69	1.003	6.27	25.1	3.76	48.08	10.87	98.24
L-12	3693	106	1.60	2.20	0.659	7.99	43.9	3.99	33.35	3.35	2.99
L-13	4397	140	10.99	1.77	0.100	5.30	56.0	3.90	11.99	3.35	0.36
L-14	4695	194	8.39	2.00	0.200	6.49	49.6	3.70	3.35	1.67	6.49
L-15	2545	112	5.74	1.50	0.200	6.99	27.9	2.99	12.98	5.99	0.50
L-16	20480	205	32.37	10.95	0.424	11.18	61.7	13.30	1.67	9.30	32.25
L-17	4147	85	11.79	2.50	0.033	6.49	46.0	4.20	1.67	1.67	9.09
Mean	9073	152	16.83	5.44	0.34	8.62	47.11	6.11	19.41	4.80	18.99
SD	8284.431	51.519	14.743	4.983	0.390	2.898	15.341	3.859	23.415	2.780	27.606

2.3 Influence of Atmospheric Pollutants on Biogeochemical Indices of Soils

As already noted, soils of tundra zone of the Taz Peninsula are characterized by relatively low taxonomic diversity. However, their combinations depending on geogenic factors of different landscapes create the very varied and complex pattern of the soil cover, which imposes certain requirements on methods of studying the changes in soils of the North and features soil sampling space model (Bashkin et al. 2012).

Among all landscape components, soils are of particular importance, as it determines the nature of the functioning of biogeochemical cycles and often serve as a biogeochemical barrier for many chemical elements (Bashkin 2006). Sleeve line, they perform important ecological landscape (and environmental protection) function. Soils and soil cover determine what vegetation will grow on them, in the absence of anthropogenic effects and corrected for them, as anthropogenesis leads to the variation of vegetation from the point of dictating the soil. The observed asynchronous changes in vegetation and soils under anthropogenic impact are mainly due to the fact, that the soils have larger characteristic time of the formatting new signs than vegetation. Therefore, there may be situations when the changes of vegetation under the new impact pronounced, while in the soil new signs cannot be observed, as insufficient time had passed for their formation. For this reason, despite the paired condition of soils and vegetation, eventually need to study them separately. It is predetermined and different biogeochemical role of these units of ecosystems.

For a long time in soil science there is a discussion about continuous-discrete nature of the tundra soils, which makes them rather complicated object to study (Geostatistics and Soil Geography 2007). There are three main approaches to the study of changing that is dictated by the rather slow speed of course of the soil-forming processes. The first is to conduct long-term periodic observations. The second and third approaches are based on comparative spatio-temporal methods (Khitrov 2008). The second approach is based on re-examination of previously studied sites, for which data have been preserved, and the results are compared between themselves. There is a major problem with inaccurate anchor points of previous studies, because at that time there was practically no global positioning systems (GPS, GLONASS), so spatial variation of soil properties and vegetative cover in most cases may overlap the dimensions have occurred over time between the observations changes. Come to the aid of remote sensing data and aerial photo survey data, but there is the problem of their low resolution and inability to field verification of the interpretation results of the images of the past. An important point is the extreme inaccessibility of aerial photographs. And if vegetative cover is not essential, since changes to the boundaries and contents of the contours are determined well, the soil is often an insurmountable obstacle, if it is impossible to use indirect evidence for the interpretation. So when you need re-dimension it is necessary to consider the existed and the existing heterogeneity of the landscape, making in many cases, more acceptable the following third method.

The third way is to choose a series of ecosystems differing in a single factor, their study provides insight into the nature of the impact of this factor, a knowledge of time within which ecosystems develop in different directions (i.e. information about the duration of the existence of soils with the occurrence of the difference by the desired factor) allows to determine the rate of change of soil (the ratio of the difference of properties and length of existence differences). This approach, despite its long history, continues to improve and at this stage due to the possibilities of geostatistics and geographic information systems (Kozlov 2005; Kozlov et al. 2006) allows obtaining results of high accuracy. Research on the effect of gas industry pollution sources on soil and biogeochemical indices were used the third method (Bashkin et al. 2012). Consider it in more detail.

Speaking on the assessment of soil variability, we can distinguish three possible options on the nature of the determination of variability, which require different approaches to study:

1. Regional and global environmental changes and their impact on ecosystems. Based on the goal, select a landscape, composed of ecosystem types, representing reliable indicators of change detected. The ecosystem/geosystem does not have to be background, and can be "hot spots of the landscape", i.e. any of the exotics that have even a small area, but very sensitive to changes in the environment (these are various ecotones—the banks, slopes, borders, liniment).
2. Ecosystem changes that occur as a response to what the impacts are generally localized, but widespread and repetitive in the desired region (roads, pipelines, wells, and agricultural impact). The selected ecosystems should be a background that reflects the modal options to allow extrapolation of findings to larger areas.
3. Need to study some invariant impact in a particular landscape in certain ecosystems, for example, the impact of any industrial facility or a geologic process (destruction of riverbank in such a case). In each of these cases you will have their own approaches to the selection of objects of study. Learning objectives are often intersecting and then using the example of the only landscape, the tasks get accomplished.

In our case it was the second task, in accordance with what was arranged for the research methodology.

Thus, the overall aim was to study the influence of objects of gas production, gas processing and gas transport infrastructure on the soil as a part of biogeochemical cycle. To solve this common problem was chosen as a model situation, namely the assessment of the impact on soil the universal gas processing complex No 2 (UCPG 2) of LLC "Gazprom Dobycha Yamburg" in the Western part of Taz peninsula, in the zone of typical tundra. This site is selected due to the fact that it describes a typical tundra landscape with numerous hazirami, and also includes gas production and gas transport infrastructure, the oldest on the Taz peninsula, which will allow to simultaneously examine the variability of soils, both in the local and in the regional coordinate system, placed in a global context. Also the materials obtained will be the basis for long-term observations of tundra ecosystems.

After selecting the area of research and subject's chosen position in the landscape, which made the initiation of the trial areas. Plots were laid in two directions—Northwest and southeast, in accordance with the wind rose in winter and summer. This was done based on the assumption that the main factor of influence of the gas treatment unit on surrounding ecosystems is aerotechnogenic one.

The impact of atmospheric pollutants on changing biogeochemical indexes of soils was studied on the nine soil profiles. Soil samples were sampled by genetic horizons, but lower depth of sampling in all soils was limited to 30 cm in order to obtain comparable data.

The geographical coordinates of the sampling of soil samples and the calculated indices of load of pollutants (Bashkin, Galiulin, Barsukov, Arabsky, Gas industry impacts on natural ecosystems) in the places of sampling are presented in Table 8.

Chemical properties of monitored tundra soils (Tables 9, 10, and 11) were generally consistent with previously published literature data on the soils of the Yamal and Taz peninsulas.

Comparison of soil properties with the level of atmospheric load was carried by the correlation method separately for the upper soil horizons and lower ones. Significant correlation between soil chemical properties and the indexes of the load of pollutants is installed only for C/N ratio in soil organic matter of forest soils (R = 0.81). For all other studied indicators reliable correlation is not obtained.

Thus, soils in high latitude ecosystems, even as scanty in the traditional sense, have a high buffering capacity towards various pollutants, compounds of which, falling on the surface of the soil, subjected to various transformation processes that contribute to both vertical and horizontal redistribution of pollutants in the soil. Along with the significant natural spatial heterogeneity of the soil cover this complicates the use of the elemental composition of soils as an indicator of atmospheric contamination.

2.4 Effect of Atmospheric Pollutants on Biogeochemical Indices of Plants

To assess the possible impact of gas production activities on the surrounding vegetation was laid three profile of 5 (for UCPG 3 and UCPG 2) and 10 (for UCPG 6) km long from the territory of the unit of complex processing of gas (UCPG) in the direction of the prevailing winds. On each profile were performed detailed vegetation description in each loop are distinguishable by eye. All descriptions were geoprivacy using a 12-channel GPS. The 62 full geobotanical descriptions of vegetation were performed. Additionally collected 87 leaves of the herbarium for further species complex taxa.

The sampling plant plots and the calculated indices atmospheric load of pollutants in the places of sampling are presented in Table 12.

Comparison of elemental composition of lichen samples we analyzed with data reported in the literature (similar lichen species in similar soil and climatic

Table 8 Conditional integral index of chemical pollution (Ip) of soils

	Pollutant deposition coefficient (Kdp)				Ip	Ip total
Sampling plot symbol	New Port	Yamburg	Tazovsky	Coefficient Kdist	Mean	Mean
s-NW-0-1	0,43	0,63	1,00	1,056	73	85
	0,69	0,70	0,65	0,144	10	
	0,25	0,68	0,42	0,027	1	
	0,39	0,54	0,75	0,013	1	
	0,61	0,65	0,83	0,014	1	
s-NW-3000-3-2	0,39	0,54	0,75	0,359	20	25
	0,67	0,76	0,77	0,056	4	
	0,30	0,56	0,46	0,016	1	
s-NW-3000-3	0,39	0,54	0,75	0,359	20	25
	0,67	0,76	0,77	0,056	4	
	0,30	0,56	0,46	0,016	1	
s-NW-4500-1	0,39	0,54	0,75	0,218	12	15
	0,67	0,76	0,77	0,036	3	
	0,30	0,56	0,46	0,013	1	
s-NW-4500-2	0,39	0,54	0,75	0,218	12	15
	0,67	0,76	0,77	0,036	3	
	0,30	0,56	0,46	0,013	1	
s-NW-5000-1	0,39	0,54	0,75	0,175	10	13
	0,67	0,76	0,77	0,030	2	
	0,50	0,74	0,75	0,011	1	
s-SE-0-1	0,85	0,85	0,72	0,947	76	93

	0,67	0,76	0,77	0,176	13	
	0,25	0,68	0,42	0,026	1	
	0,39	0,54	0,75	0,015	1	
	0,85	0,85	0,72	0,017	1	
s-SE-450-3	0,85	0,85	0,72	0,772	62	80
	0,67	0,76	0,77	0,199	15	
	0,25	0,68	0,42	0,024	1	
	0,39	0,54	0,75	0,016	1	
	0,85	0,85	0,72	0,020	2	
s-SE-750-2	0,85	0,85	0,72	0,687	55	75
	0,67	0,76	0,77	0,218	16	
	0,25	0,68	0,42	0,023	1	
	0,39	0,54	0,75	0,017	1	
	0,85	0,85	0,72	0,022	2	
Reed meadow	0,78	0,63	1,00	1,057	85	

Table 9 Analytical data of soils sampled in gas industry impacted areas

Sampling plot symbol	Soil horizon depth, cm	Id	Total content, %			Ratios			Ignition losses (IL), %	Ratio IL/C	Hydroscopic moisture, %
			N	C	P	C/N	C/P	N/P			
s-NW-0-1	0–2	85	0,322	14,162	0,0234	43,9	604	13,8	29,53	2,1	3,49
	2–5		0,508	16,364	0,0391	32,2	418	13,0	34,22	2,1	4,06
	5–30		0,068	1,442	0,0099	21,3	145	6,8	3,06	2,1	0,67
s-NW-3000-3-2	0–9	25	1,047	38,917	0,0785	37,2	496	13,3	78,16	2,0	8,74
	9–12		0,224	4,768	0,0228	21,2	209	9,8	10,37	2,2	2,16
	12–30		0,022	0,296	0,0105	13,4	28	2,1	1,44	4,9	0,91
s-NW-3000-3	0–7	25	1,071	38,037	0,0858	35,5	444	12,5	81,74	2,1	10,33
	7–17		1,957	34,536	0,1639	17,6	211	11,9	59,65	1,7	7,88
	17–30		0,084	1,375	0,0064	16,3	214	13,1	4,09	3,0	1,86
s-NW-4500-1	0–5	15	0,477	12,712	0,0446	26,7	285	10,7	26,10	2,1	3,32
	5–15		0,034	0,762	0,0063	22,5	120	5,4	1,49	2,0	0,44
	15–30		0,009	0,197	0,0027	21,9	73	3,3	0,57	2,9	0,23
s-NW-4500-2	0–4	15	0,753	23,169	0,0617	30,8	375	12,2	44,91	1,9	5,97
	4–15		0,071	1,246	0,0082	17,6	153	8,7	2,87	2,3	0,75
	15–30		0,045	0,941	0,0057	21,1	166	7,9	2,18	2,3	0,75
s-NW-5000-1	0–14	13	0,872	40,983	0,0504	47,0	814	17,3	87,87	2,1	0,88
	14–21		0,812	22,056	0,0459	27,2	481	17,7	47,96	2,2	5,37

	21–30		0,613	18,219	0,0267	29,7	683	23,0	28,64	1,6	3,93
s-SE-0-1	0–10	93	0,510	34,209	0,0467	67,1	732	10,9	66,63	1,9	7,84
	10–20		2,101	41,630	0,1046	19,8	398	20,1	71,14	1,7	7,35
	20–30		1,645	42,108	0,1104	25,6	382	14,9	88,98	2,1	10,58
s-SE-450-3	0–10	80	0,533	37,337	0,0367	70,0	1018	14,5	81,55	2,2	9,61
	10–20		1,678	40,748	0,1093	24,3	373	15,4	85,87	2,1	11,53
	20–30		0,169	2,250	0,0075	13,3	301	22,6	4,00	1,8	0,73
s-SE-750-2	0–14	75	0,935	42,223	0,0568	45,1	743	16,5	89,99	2,1	10,60
	14–20		1,467	28,493	0,0814	19,4	350	18,0	56,27	2,0	8,08
	20–30		0,694	11,725	0,0235	16,9	499	29,5	16,88	1,4	4,22
Reed meadow	0–30	85	n.d.	n.d.	0,0278	n.d.	n.d.	n.d.	20,72	n.d.	2,725

Table 10 Analytical data of soils sampled in gas industry impacted areas

Sampling plot symbol	Total P, mg/kg	Organic P, mg/kg	Inorganic P, mg/kg	Mobile P, mg P_2O_5/kg	$N-NO_3^-$, mg/kg	$N-NH_4^+$, mg/kg	Water pH	Conductivity µS/cm^2
s-NW-0-1	234,4	209,6	24,7	0,30	2,27	5,18	4,43	49,8
	391,4	372,4	19,0	0,17	1,34	1,96	4,52	44,2
	99,4	82,8	16,6	0,13	1,29	1,43	4,96	37,1
s-NW-3000-3-2	785,3	729,6	55,7	0,81	3,02	7,69	4,32	97,4
	228,0	187,7	40,3	1,21	1,64	6,43	4,88	37,9
	104,9	10,1	94,9	0,18	3,02	1,43	5,56	9,86
	56,6	35,3	21,3	0,29	1,85	1,39	4,86	11,9
s-NW-5000-1	503,6	483,8	19,9	0,26	15,45	18,15	4,13	58,2
	458,6	454,0	4,5	0,38	1,40	6,51	4,32	18,3
	266,8	262,0	4,8	0,28	1,71	2,41	4,38	27,3
s-SE-0-1	467,3	422,6	44,6	0,96	12,62	14,92	4,27	61
	1045,8	1033,8	12,0	0,50	15,41	5,89	4,59	12,66
	1103,7	1075,4	28,4	0,65	4,73	11,81	4,18	47,1
s-SE-450-3	366,9	334,1	32,8	0,23	12,62	17,09	4,27	70,3
	1092,8	1055,9	36,9	1,20	12,57	8,09	4,38	52,1
	74,7	58,3	16,4	0,63	1,34	3,36	4,86	18,02
s-SE-750-2	568,3	530,7	37,6	0,32	4,19	15,32	4,26	62,8
	814,4	766,4	48,0	0,27	3,86	13,45	4,77	50,3
	235,0	212,1	22,9	0,36	1,24	6,17	4,15	28,2
Reed meadow	278,0	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.

Table 11 Analytical data of soils sampled in gas industry impacted areas

Sampling plot symbol	Total content, mg/kg														
	K	Na	Ca	Mg	Fe	Mn	Zn	Cu	Cr	Co	Pb	Ni	Cd	Sr	Li
s-NW-0-1	9285	5292	1098	339	6340	169,7	21,4	6,19	49,92	5,39	8,69	8,29	0,200	27,96	4,49
	8150	4100	600	270	5100	110,0	19,6	6,00	17,00	1,67	7,30	8,50	0,250	10,30	3,80
	10948	4999	850	220	5199	86,0	8,0	2,60	42,99	1,67	7,10	2,60	0,170	20,80	4,60
s-NW-3000-3	646	173	1701	863	3278	128,2	35,0	7,39	35,50	5,23	3,85	17,75	0,133	16,27	0,79
	1155	209	1047	1047	12141	62,8	20,9	8,79	4,61	4,61	4,40	13,82	0,042	1,67	3,77
	11738	9141	3097	2498	19980	179,8	44,0	13,99	52,95	6,39	10,49	15,98	0,180	12,99	14,59
s-NW-5000-1	477	143	811	358	3934	30,0	18,8	4,29	43,87	2,50	2,81	8,58	0,143	7,63	0,45
	6508	4361	641	391	4827	39,3	6,2	4,66	58,26	2,50	7,66	11,15	0,333	1,67	4,16
	9045	5846	690	341	4466	51,5	7,0	5,68	81,20	1,67	7,15	3,90	0,195	1,67	5,52
s-SE-0-1	641	169	1054	537	1860	66,1	20,7	6,20	59,52	2,50	3,47	23,15	0,124	6,20	0,66
	428	170	705	221	3549	15,1	5,6	3,01	6,32	4,76	1,56	6,81	0,033	1,67	0,97
	266	198	1062	266	4950	23,2	11,6	3,19	13,04	2,50	1,35	7,92	0,048	2,61	0,68
s-SE-450-3	638	156	1825	681	1484	92,5	28,2	8,76	48,67	1,67	6,33	18,98	0,195	7,30	0,63
	482	154	1494	482	15420	33,7	20,5	3,18	1,67	4,10	2,41	9,01	0,096	4,67	1,06
	11339	6194	1249	295	5245	86,9	10,5	3,50	10,39	1,67	6,39	4,80	0,265	42,96	5,79
s-SE-750-2	574	140	1236	466	2005	20,5	18,7	2,19	4,20	5,60	2,01	6,06	0,163	9,33	0,61
	1199	203	461	876	20756	28,6	14,3	4,43	26,29	2,68	2,31	8,03	0,033	1,67	3,00
	10877	9797	1079	1661	22833	152,8	36,2	16,27	66,42	8,30	8,97	27,90	0,166	8,30	14,78
Reed meadow	11236	4873	1208	785	18425	335	27,59	12,79	1,67	10,07	11,28	50,95	0,033	28,70	10,27

Table 12 Conditional integral index of chemical pollution (Ip) of plants

Sampling plot symbol	Pollutants deposition coefficient (Kdp)			Coefficient Kdist	Ip	Ip total
	New Port	Yamburg	Tazovsky		Mean	
p-NW-0	0.43	0.63	1.00	1.052	72	85
	0.25	0.68	0.42	0.027	1	
	0.69	0.70	0.65	0.143	10	
	0.39	0.54	0.75	0.013	1	
	0.61	0.65	0.83	0.014	1	
p-NW-360	0.43	0.63	1.00	0.928	64	75
	0.25	0.68	0.42	0.027	1	
	0.69	0.70	0.65	0.129	9	
	0.39	0.54	0.75	0.012	1	
	0.61	0.65	0.83	0.013	1	
p-NW-500	0.39	0.54	0.75	0.827	46	57
	0.25	0.68	0.42	0.025	1	
	0.67	0.76	0.77	0.115	8	
	0.39	0.54	0.75	0.011	1	
	0.61	0.65	0.83	0.013	1	
p-NW-1000	0.39	0.54	0.75	0.629	35	44
	0.30	0.56	0.46	0.022	1	
	0.67	0.76	0.77	0.091	7	
	0.39	0.54	0.75	0.009	0	
	0.61	0.65	0.83	0.011	1	
p-NW-3000	0.39	0.54	0.75	0.358	20	25
	0.30	0.56	0.46	0.016	1	
	0.67	0.76	0.77	0.056	4	
p-NW-5000	0.39	0.54	0.75	0.176	10	13
	0.30	0.56	0.46	0.011	1	
	0.67	0.76	0.77	0.030	2	
p-SE-0	0.85	0.85	0.72	0.944	76	92
	0.25	0.68	0.42	0.026	1	
	0.67	0.76	0.77	0.176	13	
	0.39	0.54	0.75	0.015	1	
	0.61	0.65	0.83	0.017	1	
p-SE-500	0.85	0.85	0.72	0.777	63	80
	0.25	0.68	0.42	0.024	1	
	0.67	0.76	0.77	0.198	15	
	0.39	0.54	0.75	0.016	1	
	0.61	0.65	0.83	0.020	1	
p-SE-750	0.85	0.85	0.72	0.704	57	76
	0.25	0.68	0.42	0.024	1	
	0.67	0.76	0.77	0.213	16	
	0.39	0.54	0.75	0.017	1	

(continued)

Table 12 (continued)

Sampling plot symbol	Pollutants deposition coefficient (Kdp)			Coefficient Kdist	Ip	Ip total
	New Port	Yamburg	Tazovsky		Mean	
	0.61	0.65	0.83	0.022	2	

Note: Plant samples of Alectoria ochroleuca, Alectoria nigricans, leaves and branches of Betula nana picked from the same places

conditions). It can be noted that overall, in the lichen on the territory of LLC "Gazprom Dobycha Yamburg" was observed the increased content of chromium, potassium, magnesium, and nickel (Tables 13, 14, and 15).

Correlation analysis of the elemental composition of plants with calculated indexes of the load of pollutants allowed establishing that with increase of load index atmospheric pollutants is significantly higher:

– chromium content in the lichen Alectoria ochroleuca (R = 0.78)
– content of phosphorus (R = 0.58), copper (R = 0.86) and nickel (R = 0.84) in the leaves of the dwarf birch
– the content of phosphorus (R = 0.70) in the branches of the dwarf birch.

Interestingly, the content of copper in the branches of the dwarf birch is negatively correlated with the index of the load of pollutants (R = –0.74). Thus, there is active translocation of copper by plant organs (branches—leaves) and the level of pollution directly or indirectly affects this process.

2.5 Assessment of the Impact of Emissions from the UCPG 2 on Plant Development

During the field season of 2010 measuring the height of lichens on the two transects (along the wind rose from UCPG 2) located near camp Yamburg was carried out. The following results were obtained:

1. the range of heights of lichen at a distance of 200–500 m from UCPG 2 = 9–12 cm,
2. at a distance of 1 km = 5–6 cm,
3. in undisturbed tundra = 4–6 cm.

This applies to both investigated (the most common) lichens: *Alectoria ochroleuca* and *Alectoria nigricans*.

The content of both the major biological elements (nitrogen and phosphorus) in two lichen species decreases dramatically as the distance from UCPG 2 in most cases (Table 16).

The most contrasting differences were obtained for species *Alectoria nigricans*, which can then be used as the main indicator species. The analysis of

Table 13 Analytical results of plants sampled in gas industry impacted areas

Sampling plot symbol	Id	Total content, %			Total, %	Ratio N/P	Ratio C/N
		C	H	N			
Alectoria ochroleuca							
p-NW-0	85	44.29	6.25	0.34	0.017	20.0	130
p-NW-360	75	44.15	6.26	0.39	0.023	16.4	115
p-NW-500	57	43.84	6.16	0.36	0.028	13.0	122
p-NW-1000	44	43.22	6.21	0.34	0.027	12.4	129
p-NW-3000	25	43.62	6.16	0.33	0.021	15.7	134
p-NW-5000	13	45.60	6.36	0.33	0.011	30.3	138
p-SE-0	92	41.98	5.78	0.39	0.028	13.9	109
p-SE-500	80	44.91	6.16	0.32	0.012	27.3	140
p-SE-750	76	44.83	6.29	0.36	0.020	17.9	125
Alectoria nigricans							
p-NW-0		42.48	6.40	0.32	0.016	20.5	133
p-NW-5000		43.12	6.53	0.35	0.026	13.4	123
Mean		**43.820**	**6.230**	**0.346**	**0.021**	**16.7**	**127**
SD		**1.086**	**0.189**	**0.024**	**0.006**	**5.926**	**9.621**
Betula nana, leaves							
p-NW-0	85	49.07	6.31	1.69	0.203	8.3	29
p-NW-360	75	48.85	6.16	1.80	0.275	6.6	27
p-NW-500	57	49.05	6.31	1.64	0.258	6.3	30
p-NW-1000	44	49.75	6.40	1.51	0.094	16.1	33
p-NW-3000	25	49.73	6.32	1.31	0.152	8.6	38
p-NW-5000	13	50.44	6.33	1.45	0.133	10.9	35
p-SE-0	92	49.49	6.52	1.63	0.347	4.7	30
p-SE-500	80	49.86	6.45	1.29	0.180	7.2	39
p-SE-750	76	49.84	6.54	1.54	0.362	4.3	32
Mean		**49.564**	**6.371**	**1.540**	**0.223**	**6.9**	**32**
SD		**14.553**	**1.863**	**0.573**	**0.119**	**4.230**	**30.031**
Betula nana, branches							
p-NW-0	85	55.95	6.73	0.97	0.125	7.7	58
p-NW-360	75	53.21	6.62	0.91	0.116	7.8	58
p-NW-500	57	53.62	6.87	0.95	0.112	8.5	56
p-NW-1000	44	52.14	6.73	1.07	0.083	12.8	49
p-NW-3000	25	53.89	7.03	0.79	0.093	8.5	68
p-NW-5000	13	54.45	7.06	1.04	0.066	15.8	52
p-SE-0	92	52.92	6.92	1.14	0.117	9.7	46
p-SE-500	80	52.59	6.91	1.09	0.078	13.9	48
Betula nana, branches							
p-SE-750	76	53.76	6.80	1.02	0.116	8.8	53
Mean		**53.614**	**6.852**	**0.998**	**0.101**	**9.9**	**54**
SD		**11.762**	**1.502**	**0.237**	**0.041**	**3.377**	**11.182**

Table 14 Analytical results of plants sampled in gas industry impacted areas

Sampling plot symbol	Ignition losses (IL), %	Ash content, %	Ratio IL/C	Total content, mg/kg			
				K	Na	Ca	Mg
Alectoria ochroleuca							
p-NW-0	99.0	1.01	2.24	454	26	157	67
p-NW-360	98.25	1.75	2.23	504	36	251	104
p-NW-500	96.9	3.06	2.21	485	39	291	119
p-NW-1000	97.7	2.30	2.26	364	23	146	58
p-NW-3000	99.0	1.00	2.27	772	40	423	131
p-NW-5000	99.7	0.33	2.19	704	45	283	111
p-SE-0	97.3	2.74	2.32	529	44	416	140
p-SE-500	99.1	0.87	2.21	917	61	694	223
p-SE-750	99.1	0.91	2.21	734	44	473	170
Alectoria nigricans							
p-NW-0	99.1	0.94	2.33	586	31	346	138
p-NW-5000	99.2	0.75	2.30	1160	37	402	195
Mean	**98.58**	**1.42**	**2.25**	**655**	**39**	**353**	**132**
SD	**0.898**	**0.898**	**0.049**	**233.118**	**10.316**	**155.795**	**49.862**
Betula nana, leaves							
p-NW-0	93.6	6.39	1.91	6419	57	2611	1500
p-NW-360	94.3	5.67	1.93	2897	64	2549	1535
p-NW-500	94.8	5.19	1.93	2237	38	1992	1214
p-NW-1000	96.1	3.94	1.93	2938	54	3186	1636
p-NW-3000	97.2	2.84	1.95	2460	53	2698	1556
p-NW-5000	95.4	4.60	1.89	2130	52	2475	1511
p-SE-0	94.3	5.69	1.91	4168	113	3349	1973
p-SE-500	95.8	4.19	1.92	3037	66	3416	2365
Betula nana, leaves							
p-SE-750	96.1	3.94	1.93	3280	77	3067	2181
Mean	**95.28**	**4.72**	**1.92**	**3285**	**64**	**2816**	**1719**
SD	**1.112**	**1.112**	**0.018**	**1325.238**	**21.258**	**469.838**	**372.434**
Betula nana, branches							
p-NW-0	97.2	2.76	1.74	1387	34	1403	550
p-NW-360	97.7	2.32	1.84	1631	42	1223	587
p-NW-500	93.6	6.38	1.75	2028	74	1590	725

(continued)

Table 14 (continued)

Sampling plot symbol	Ignition losses (IL), %	Ash content, %	Ratio IL/C	Total content, mg/kg			
				K	Na	Ca	Mg
p-NW-1000	97.0	2.98	1.86	1451	59	1884	494
p-NW-3000	98.6	1.39	1.83	1364	30	1271	447
p-NW-5000	98.2	1.78	1.80	1534	38	1746	522
p-SE-0	96.3	3.71	1.82	1292	42	946	403
p-SE-500	98.0	1.95	1.86	1432	39	1699	563
p-SE-750	98.6	1.43	1.83	1013	38	792	393
Betula nana, leaves							
Mean	**97.26**	**2.74**	**1.81**	**1459**	**44**	**1395**	**520**
SD	**1.561**	**1.561**	**0.045**	**274.031**	**14.054**	**371.221**	**102.985**

samples of lichen, remote at a distance of 500 m from UCPG 2 in the direction East, also showed a strong influence of UCPG 2, comparable to the towards the South. Samples of lichen removed by the same distance (500 m), but in other directions (against prevailing winds) showed low values and the content of nitrogen and phosphorus (Fig. 1).

Considering both indicators—elevated concentrations of both elements in the lichens and their height (and, consequently, total biomass) in the areas adjacent to UCPG 2, we can see a very significant influence of UCPG on the productivity of lichens and, in general, on the functioning of tundra ecosystems. The expert can estimate that the accumulation of nitrogen and phosphorus in the total biomass of lichens in the radius of 200 m from UCPG 2 (in the directions of prevailing winds) compared with that at a distance of 3 km is increased as follows (Table 17).

3 Conclusions

Thus, field monitoring of modern biogeochemical cycling in gas industry impacted areas did not appear any strong remarkable alterations in studied biogeochemical system: surface waters-bottom sediments-plants. In the contrary, we can see a very significant influence on the productivity of lichens and, in general, on the functioning of tundra ecosystems.

Table 15 Analytical results of plants sampled in gas industry impacted areas

Sampling plot symbol	Total content, mg/kg										
	Fe	Mn	Zn	Cu	Cr	Co	Pb	Ni	Cd	Sr	Li
Alectoria ochroleuca											
p-NW-0	119	16	6	0.70	1.64	0.09	0.79	1.61	0.03	0.28	0.06
p-NW-360	198	35	6.7	0.77	2.35	0.29	0.96	2.20	0.04	0.16	0.14
p-NW-500	232	44	7	0.64	2.60	0.33	0.78	2.35	0.03	0.05	0.13
p-NW-1000	93	20	5	0.40	1.26	0.04	0.46	1.17	0.02	0.04	0.06
p-NW-3000	125	54	12	1.04	1.64	0.17	1.39	2.09	0.06	0.85	0.09
p-NW-5000	8	22	10	3.08	0.05	0.15	0.93	1.39	0.10	1.46	0.06
p-SE-0	194	59	10	0.88	2.86	0.19	1.06	2.40	0.05	1.13	0.12
p-SE-500	117	73	18	2.06	2.34	0.12	1.75	2.38	0.10	1.44	0.09
p-SE-750	52	52	14	3.62	2.94	0.11	1.21	3.36	0.05	0.53	0.07
Alectoria nigricans											
p-NW-0	107	40	16	1.64	3.40	0.54	2.54	2.85	0.09	1.43	0.15
p-NW-5000	120	72	16	2.04	2.58	0.20	2.73	2.15	0.18	0.89	0.10
Mean	**124**	**44**	**11**	**1.53**	**2.15**	**0.20**	**1.33**	**2.18**	**0.07**	**0.75**	**0.10**
SD	**64.828**	**19.766**	**4.489**	**1.064**	**0.942**	**0.139**	**0.731**	**0.628**	**0.047**	**0.567**	**0.034**
Betula nana, Leaves											
p-NW-0	151	1218	95	2.92	1.46	0.29	0.45	3.60	0.19	7.50	0.19
p-NW-360	6	508	87	2.75	0.14	0.43	0.16	4.35	0.06	3.33	0.17
p-NW-500	3	400	60	1.58	0.09	0.09	0.19	2.63	0.10	2.35	0.17
p-NW-1000	44	1399	129	2.09	1.08	0.11	0.33	2.58	0.27	6.67	0.28
p-NW-3000	39	780	116	1.82	1.33	0.11	0.26	2.04	0.17	6.46	0.19
p-NW-5000	37	370	109	1.67	1.55	0.12	0.23	1.78	0.10	6.54	0.13
p-SE-0	17	511	124	3.56	2.08	0.97	0.47	5.84	0.12	3.61	0.28

Table 15 (continued)

Sampling plot symbol	Total content, mg/kg										
	Fe	Mn	Zn	Cu	Cr	Co	Pb	Ni	Cd	Sr	Li
Betula nana, leaves											
p-SE-500	4	730	175	3.21	1.17	0.10	0.49	4.38	0.39	7.69	0.32
p-SE-750	7	361	120	3.44	1.87	0.49	0.44	2.79	0.14	0.82	0.15
Mean	**34**	**698**	**113**	**2.56**	**1.20**	**0.30**	**0.34**	**3.33**	**0.17**	**5.00**	**0.21**
SD	**46.839**	**379.159**	**31.882**	**0.782**	**0.689**	**0.296**	**0.130**	**1.317**	**0.102**	**2.499**	**0.067**
Betula nana, branches											
p-NW-0	91	218	155	3.04	5.60	0.37	0.68	9.39	0.37	4.48	0.18
p-NW-360	223	227	130	3.37	5.60	0.27	0.45	7.67	0.20	2.12	0.18
p-NW-500	345	398	178	3.88	7.86	0.62	0.73	8.18	0.36	5.21	0.21
p-NW-1000	141	222	141	3.43	5.34	0.30	0.67	7.66	0.33	6.65	0.17
p-NW-3000	29	226	122	3.98	2.93	0.17	0.42	3.92	0.35	4.58	0.09
p-NW-5000	53	113	196	7.02	2.28	0.41	0.92	3.18	0.20	8.04	0.10
p-SE-0	291	367	141	3.15	6.34	0.33	0.54	5.17	0.11	1.64	0.11
Betula nana, leaves											
p-SE-500	181	382	177	4.10	1.24	0.05	0.43	6.40	0.43	6.49	0.19
p-SE-750	74	151	113	2.50	1.31	0.18	0.42	2.26	0.17	0.95	0.06
Mean	**159**	**256**	**150**	**3.83**	**4.28**	**0.30**	**0.58**	**5.98**	**0.28**	**4.46**	**0.14**
SD	**110.206**	**102.705**	**28.102**	**1.298**	**2.387**	**0.164**	**0.177**	**2.471**	**0.111**	**2.450**	**0.053**

Note: CHNS analyzer

Table 16 Changes in the content of nitrogen and phosphorus in lichens with distance from UCPG 2

Lichen species	Transect direction	Distance from UCPG 2, m	N, %	P, %
Alectoria nigricans	To south	200	0,354	0,209
		500	0,185	0,146
		3000	0,057	0,029
Alectoria ochroleuca	To south	200	0,147	0,030[a]
		500	0,117	0,053
		3000	0,100	0,015
	To west	500	0,087	0,017
	To north		0,091	0,077[b]
	To east		0,123	0,056

Note: as exception to the general rule were two samples: [a]where it was expected a significantly high concentration of phosphorus at the level of 0,08–0,10 %, [b]where the expected lower concentrations of phosphorus level is 0,015–0,020 %

Table 17 Increasing accumulations of nitrogen and phosphorus in the total biomass of lichens in the radius of 200 m from UCPG 2 (in the directions of prevailing winds) compared with that at a distance of 3 km

Lichen species	Transect direction	Increase, times	
		Nitrogen	Phosphor
Alectoria nigricans	To south	13,5	15,7
Alectoria ochroleuca	To south	3,3	4,4

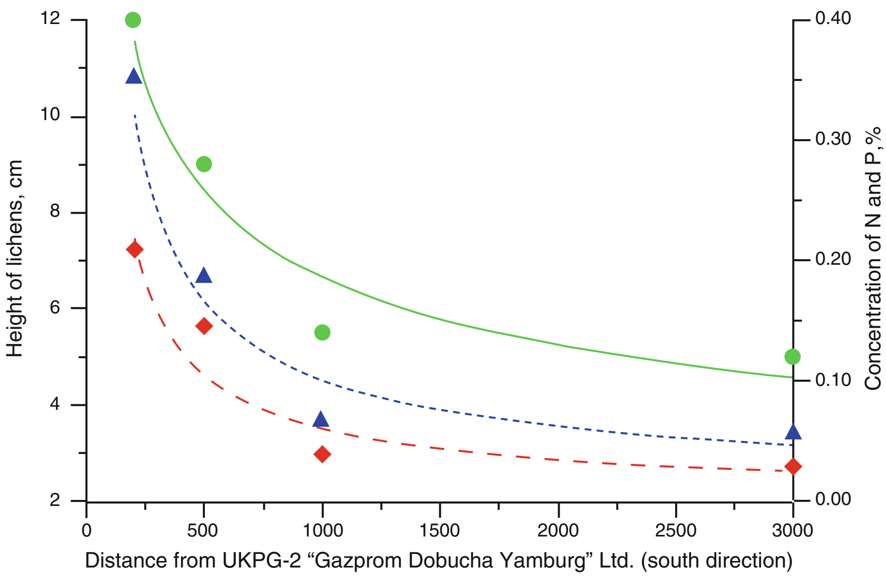


Fig. 1 Decrease of the height of the lichen *Alectoria nigricans* and content of the most important nutrients in the plant as the distance from UCPG 2 in the gas industry impacted area

References

Arestova, I. A. (2003). *Estimation of stability of tundra ecosystems using phytoindication and geochemical indicators*. Abstract of dissertation for candidate of geographical sciences. St. Petersburg: St. Petersburg State University Press, 24pp.

Bashkin, V. N. (2006). *Modern biogeochemistry: Environmental risk assessment* (2nd ed.). New York: Springer. 444 pp.

Bashkin, V. N., & Kasimov, N. S. (2004). *Biogeochemistry*. Moscow: Scientific World. 634pp.

Bashkin, V. N., Arno, A. B., Arabsky, A. K., Barsukov, P. A., Priputina, I. V., & Galiulin, R. V. (2012). *Retrospective and forecast of geoecological situation on the gas condensate fields of the far north*. Moscow: Gazprom VNIIGAZ. 280pp.

Dorozhukova, L. S., & Yanin, E. P. (2004). *Environmental problems of oil producing areas in the Tyumen region*. Moscow: IMGRE Press. 56pp.

Geostatistics and Soil Geography. (2007). P. V. Krasilnikov (Ed.). Moscow: Nauka, 175pp.

Khitrov, N. B. (2008). An approach to retrospective estimation of the change of state of soils. *Eurasian Soil Science, 8*, 899–912.

Kozlov, D. N. (2005). The assessment of landscape components based on the analysis of remote sensing data, digital elevation models and field descriptions. In Y. G. Puzachenko (Ed.), *Environmental management* (pp. 202–205). Moscow: Publishing House of Moscow State University.

Kozlov, D. N., Puzachenko, M. Y., Fedyaev, V. M., & Puzachenko, Y. G. (2006). Identification of landscape factors on the basis of field studies and remote information. In Y. G. Puzachenko (Ed.), *Landscape science: Theory, methods, regional studies, practice* (pp. 103–105). Moscow: Geographical Faculty of Moscow State University.

Moskovchenko, D. V. (2010). *Geochemistry of landscapes of the north of the west Siberian plain: Structural-functional organization of geosystems and problems of ecodiagnostic*. Abstract of dissertation on competition of a scientific degree of the doctor of geographical Sciences. Saint Petersburg: Saint-Petersburg State University Press, 33pp.

Perelman, A. I., & Kasimov, N. S. (1999). *Landscape geochemistry*. Moscow: Astreya-2000. 763pp.

Sorokina, E. P., Dmitrieva, N. K., & Karpov, L. K. (2001). Analysis of regional geochemical background as the basis of ecological and geochemical mapping of lowland areas: The example of the Northern part of the West Siberian region. *Applied Geochemistry. Environmental Geochemistry, 2*, 316–338.

Emission of Carbon Dioxide and Methane in Gas Industry Impacted Ecosystems

Vladimir N. Bashkin and Pavel A. Barsukov

Abstract The paper results showed that in field studies in gas industry impacted tundra ecosystems the positive relationship between the level of atmospheric pollutants and the rate of emission as carbon dioxide and methane from zonal ecosystem has not been established. The values of fluxes of these greenhouse gases confirm the high spatial and temporal variability of the studied parameters for tundra ecosystems and are consistent with the literature data. Average (over study period) CO_2 flow value was 158 mg $CO_2/m^2/h$. This value lies within the emission of carbon dioxide received for tundra ecosystems of Western Zemlya and Taimyr tundra. Flow of methane was characterized by a low rate of emission, averaging 0.063 mg $CH_4/m^2/h$, which indicates the absence of significant sources of methane in the studied soils. Therefore, in the given conditions was not marked remarkable changes in the biogeochemical cycle of carbon.

Keywords Emission of carbon dioxide and methane • Gas industry impacted tundra ecosystems • Carbon biogeochemical cycle

1 Introduction

The flow of carbon dioxide and methane, as the major greenhouse gases, from the soil into the atmosphere or into the soil from the atmosphere depends on the activity of soil microorganisms and plants in the case of carbon dioxide. From the resultant speed of processes for the uptake and release of carbon-containing gases "from" and

V.N. Bashkin (✉)
Institute of Physicochemical and Biological Problems of Soil Sciences of Russian Academy of Sciences, Pushchino, Moscow Region 142290, Russian Federation

Institute of Natural Gases and Gas Technologies—Gazprom VNIIGAZ LLC, Razvilka, Moscow Region 142719, Russian Federation
e-mail: bashkin@issp.serpukhov.su

P.A. Barsukov
Institute of Soil Science and Agrochemistry of Siberian Branch of Russian Academy of Sciences, Novosibirsk 630099, Russian Federation

V.N. Bashkin (ed.), *Biogeochemical Technologies for Managing Pollution in Polar Ecosystems*, Environmental Pollution 26, DOI 10.1007/978-3-319-41805-6_5

"to" biogeochemical system "soil–plants" we can conclude, whether or not a particular terrestrial ecosystem is a source or a sink of carbon. In the first case we note a net emissions, in the second—sequestration.

In biogeochemical cycle of carbon against carbon dioxide processes such as photosynthesis by plants and some representatives of the soil microbiota provide a sink for atmospheric carbon, and respiration of plant roots and heterotrophic soil respiration is its emission from the soil. Similarly, in the case of methane multidirectional processes are responsible for its balance in Arctic ecosystems. There are ecological relations between climate characteristics and processes of production and consumption of methane in natural ecosystems and major affecting factors are vegetation, evapotranspiration and evaporation (Bashkin et al. 2012). The interaction of environmental factors affects the temperature and soil moisture, and therefore, the status of aeration. Aerobic processes, methane oxidation (methane consumption) and anaerobic process of methane production (methanogenesis) have a high dependence on soil moisture status and aeration, which, in turn, depends on the general climatic parameters. The balance between these two bacterial processes determines the net flux of methane into the soil or out of it.

In addition to natural factors in gas industry impacted areas we should as well consider the possible influence of anthropogenic emissions due to technological processes. This possibility has been estimated in our field monitoring studies in the vicinities of the Processing plant-2 of "Gazprom Dobycha Yamburg" LLC, as the main gas production branch of Gazprom company in Polar region of Russia.

2 Materials and Methods

The study of the emission of carbon greenhouse gases (CO_2 and CH_4) in gas industry impacted tundra ecosystems was carried out by closed-chamber technique based on the static Makarov's method (Lopez de Gerenyu et al. 2001), taking into account the accumulation of carbon in the chamber insulator.

Measurements of fluxes of carbon dioxide and methane in the impacted area of Processing plant-2 of "Gazprom Dobycha Yamburg" LLC were carried out from 11th to 15th of August 2011 by a method of ground-based cameras of volume 60.85 L. During exposure, air samples were taken from the chambers every 10 min (0, 10, 20 and 30 min from the beginning of the experiment). The gas analysis was performed on the chromatograph Crystal—5000 (Chromatec, Russia) with a flame ionization detector and methanizer. Calculation of fluxes of CH_4 and CO_2 were performed using a linear regression model of accumulation of each component in the closed volume of the chamber (Sabrekov et al. 2011).

Exposure chambers were located at different distances from Processing plant-2, as shown in Fig. 1. The fluxes of CH_4 and CO_2, measured on distance of 5000 m from Processing plant-2, were considered as the background.

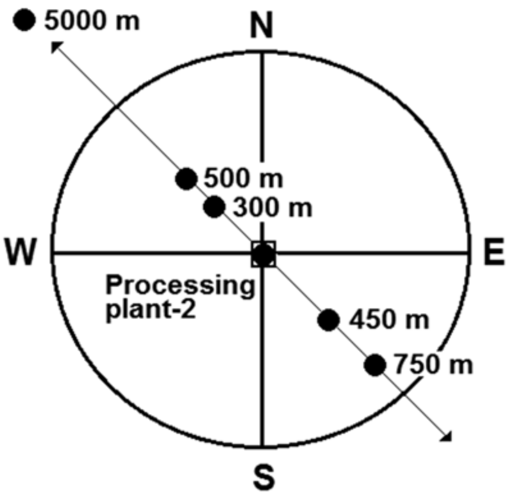


Fig. 1 Location map of exhibition chambers in the impacted area of Processing plant-2 of "Gazprom Dobycha Yamburg" LLC

Table 1 Coordinates of the sites of installation of closed chambers, the load index of pollutants near Processing plant-2 and relevant soil types

Plot symbol	Plot coordinates		Ip	Soil type (Russian classification)
	North latitude	East meridian		
ch-NW-0	67.97771	75.41923	85	Podbur podzolic gleyed crioturbated
ch-NW-360	67.98024	75.41431	75	Peaty eutrophic criozem
ch-NW-500	67.98007	75.40451	57	Peaty-criozem roughly humuced
ch-NW-5000	67.99728	75.31032	13	Peaty-criozem
ch-SE-0	67.97160	75.42641	92	Peaty-gleezem permafrost
ch-SE-450	67.96690	75.42928	80	Peaty-creozem gleyed crioturbated
ch-SE-750	67.96436	75.43312	76	Peaty eutrophic criozem

Note: the installation location of the closed chambers is almost equal to the selection of plant samples

Coordinates of the sites of installation of closed chambers, the load index of pollutants (see Bashkin, Galiulin, Barsukov, Arabsky, Gas industry impacts on natural ecosystems) near Processing plant-2 and relevant soil types are given in Table 1.

The closed chambers were mounted on aligned micro- and nanorelief areas with approximately the same plant community. In all cases the projective cover was as follows:

- lichens—75–95 %, in most cases about 80 %;
- moss is 2–8 %, in most cases, about 5 %;
- dwarf birch—5–10 %;
- sedge—1–5 %, in most cases about 2–3 %.

Among lichens, undoubtedly, dominated by *Alectoria ochroleuca*, which occupied 60–70 % of all lichens, and only at the point ch-360—40–50 %.

3 Results

The results of monitoring studies are presented in Tables 2 (in dynamics during the day) and 3—in amount per day. The rate of release of methane is determined by local conditions. Analysis of the obtained data showed that relative to the selected Processing plant-2 transect significant sources of methane do not exist. The average flux of methane $\bar{E} \pm SD$ (mg $CH_4/m^2/h$) was characterized by low velocity emission (0.05 ± 0.28, $n = 90$).

The presence of sandy sediments and the elevation of the area near the Processing plant-2 apparently do not contribute to the development of the processes of methanogenesis. The similar estimated fluxes of methane were obtained in relatively dry areas of south tundra near Vorkuta (Heikkinen et al. 2004). This was observed both as the release of methane and uptake. The average CH_4 flux was close to zero. Similar values of methane emission observed for peat mounds and hummocks in the southern tundra of Western Siberia (Shnyrev and Glagolev 2007).

For wet tundra are usually observed higher values of methane emission: 0.2–7.6 mg $CH_4/m^2/h$ (Kutzbach et al. 2007), 0.7–3.2 mg $CH_4/m^2/h$ (Omelchenko 1994; Nakano et al. 2001, 2004). In tundra boggy area, the average methane flux during the warm period of the year amounted to 0–7.0 mg $CH_4/m^2/h$ and carbon dioxide up to 200 mg $CO_2/m^2/h$ (Glagolev and Smagin 2006).

The release of carbon dioxide into the atmosphere at the studied landfill is mainly due to the respiration of plants. There is a much higher rate of CO_2 emission in mid-day (13–15 h) and a noticeable decrease in the evening hours. The distribution of CO_2 flows in the direction of transect, apparently, determined by the nature of the vegetation cover in the monitoring area. In the Southeast direction from Processing plant-2 total "breath" is somewhat lower than in a Northwesterly direction. This difference is obviously due to the natural diversity of soil and plant cover of tundra ecosystems.

A similar increase of total respiration in the daytime was observed in tundra biogeocenoses of Taimyr and West Zemlya tundra (Zamolodchikov et al. 1997). Total carbon dioxide emissions in ecosystems of the southern tundra, evaluated by these authors, were in the range from 86.7 to 169 mg $CO_2/m^2/h$. We should also mention that the magnitude of the CO_2 streams registered 11–15 August 2011 near Processing plant-2 (see Table 2) confirm the high spatial and temporal variability of the studied parameters for tundra ecosystems and are consistent with the literature data.

4 Conclusions

Thus, the positive relationship between the level of anthropogenic pollution and the rate of emission both carbon dioxide and methane from tundra zonal ecosystem has not been established. The values of fluxes of these greenhouse gases confirm the high spatial and temporal variability of the studied parameters for tundra ecosystems and are consistent with the literature data. Average (over study period) CO_2

Table 2 Results of measurements of the carbon dioxide and methane emissions (the dynamics during the day) in the district of Processing plant-2, August 2011 (mg/m²/h)

Date	Direction	Time	Soil temperature, °C	CH_4, mg/m²/h	CO_2, mg/m²/h
11/08/2011	NW, 0 m	19:00	8	0	38.1
11/08/2011	NW, 0 m	17:45	8	–0.06	132.4
11/08/2011	NW, 0 m	19:45	8	–0.45	n.s.
11/08/2011	NW, 500 m	15:00	3	–0.01	217.7
11/08/2011	NW, 500 m	17:00	3	0	145.9
11/08/2011	NW, 500 m	19:00	3	–0.01	9.7
11/08/2011	NW, 500 m	15:45	3	–0.17	102.1
11/08/2011	NW, 500 m	17:45	3	–0.02	n.s.
11/08/2011	NW, 500 m	19:45	3	0.03	34.6
11/08/2011	NW, 5000 m	15:00	16	–0.07	n.s.
11/08/2011	NW, 5000 m	17:00	9	0.12	40.4
11/08/2011	NW, 5000 m	19:00	9	0.2	526
12/08/2011	NW, 0 m	13:00	8	0.22	799.5
12/08/2011	NW, 0 m	15:00	9	0.18	619.4
12/08/2011	NW, 0 m	17:00	9.5	0.1	77.3
12/08/2011	NW, 0 m	19:00	9.5	–0.06	n.s.
12/08/2011	NW, 0 m	13:45	8.5	–0.01	n.s.
12/08/2011	NW, 0 m	17:45	9.5	–0.08	176.3
12/08/2011	NW, 0 m	19:45	9.5	12.1	118.5
12/08/2011	NW, 300 m	13:00	6	–0.41	n.s.
12/08/2011	NW, 300 m	15:00	6	–0.28	n.s.
12/08/2011	NW, 300 m	17:00	6.5	0.27	655
12/08/2011	NW, 300 m	19:00	7	1.56	n.s.
12/08/2011	NW, 300 m	13:45	6	0.08	583.6
12/08/2011	NW, 300 m	15:45	6.5	0.14	284.4
12/08/2011	NW, 300 m	17:45	6.5	0.12	347.3
12/08/2011	NW, 300 m	19:45	7	0.43	n.s.
12/08/2011	NW, 500 m	13:00	2.5	0.03	37.5
12/08/2011	NW, 500 m	15:00	2.5	–0.04	40.5
12/08/2011	NW, 500 m	17:00	2.5	–0.06	161.3
12/08/2011	NW, 500 m	19:00	3	0.16	236.7
12/08/2011	NW, 500 m	13:45	2.5	–0.01	22.7
12/08/2011	NW, 500 m	15:45	2.5	0.19	295
12/08/2011	NW, 500 m	17:45	2.5	0.08	36.9
12/08/2011	NW, 500 m	19:45	3	–0.02	132.1
12/08/2011	NW, 5000 m	13:00	6	–0.45	43.7
12/08/2011	NW, 5000 m	15:00	7	–0.22	n.s.
12/08/2011	NW, 5000 m	17:00	8	–0.1	n.s.
12/08/2011	NW, 5000 m	19:00	9	0.29	263.8
12/08/2011	NW, 5000 m	13:45	6.5	0	33.1

(continued)

Table 2 (continued)

Date	Direction	Time	Soil temperature, °C	CH_4, mg/m²/h	CO_2, mg/m²/h
12/08/2011	NW, 5000 m	15:45	7	0.32	128.6
12/08/2011	NW, 5000 m	17:45	8	0.23	105.7
12/08/2011	NW, 5000 m	19:45	9	0.69	82.7
14/08/2011	SE, 0 m	13:00	5	0.21	67.3
14/08/2011	SE, 0 m	15:00	5	–0.05	208.4
14/08/2011	SE, 0 m	17:00	5	0.03	71.1
14/08/2011	SE, 0 m	19:00	5	–0.13	75.8
14/08/2011	SE, 0 m	13:45	5	–0.28	153.3
14/08/2011	SE, 0 m	15:45	5	–0.22	120.8
14/08/2011	SE, 0 m	17:45	5	–0.5	52.3
14/08/2011	SE, 0 m	19:45	5	–0.04	42.5
14/08/2011	SE, 450 m	13:00	3	0.16	96.2
14/08/2011	SE, 450 m	15:00	3	0.06	137
14/08/2011	SE, 450 m	17:00	3	0.07	59.6
14/08/2011	SE, 450 m	19:00	3	0.42	65.6
14/08/2011	SE, 450 m	13:45	3	0.16	14.1
14/08/2011	SE, 450 m	15:45	3	0.08	85.9
14/08/2011	SE, 450 m	17:45	3	0.36	70
14/08/2011	SE, 450 m	19:45	3	0.08	37.6
14/08/2011	SE, 750 m	13:00	6	–0.22	n.s.
14/08/2011	SE, 750 m	15:00	6	–0.35	n.s.
14/08/2011	SE, 750 m	17:00	6	0.35	290.4
14/08/2011	SE, 750 m	19:00	6	–0.18	168
14/08/2011	SE, 750 m	13:45	6	–0.1	155.5
14/08/2011	SE, 750 m	15:45	6	0.53	n.s.
14/08/2011	SE, 750 m	17:45	6	–0.8	n.s.
14/08/2011	SE, 750 m	19:45	6	0.1	114
15/08/2011	SE, 0 m	13:05	4	0.09	121.3
15/08/2011	SE, 0 m	15:00	5	0.17	56.2
15/08/2011	SE, 0 m	17:00	5	0.04	83.5
15/08/2011	SE, 0 m	19:00	5	0.1	17.1
15/08/2011	SE, 0 m	13:50	4.5	0.03	53.6
15/08/2011	SE, 0 m	15:45	5	0.04	96.3
15/08/2011	SE, 0 m	17:45	5	0.1	26.8
15/08/2011	SE, 0 m	19:45	5	0.03	47.4
15/08/2011	SE, 450 m	13:05	2	0.04	n.s.
15/08/2011	SE, 450 m	15:00	2	0.67	170.5
15/08/2011	SE, 450 m	17:00	2	0.22	86.5
15/08/2011	SE, 450 m	19:00	2	–0.1	n.s.
15/08/2011	SE, 450 m	13:50	2	0.06	80.7
15/08/2011	SE, 450 m	15:45	2	0.33	411

(continued)

Table 2 (continued)

Date	Direction	Time	Soil temperature, °C	CH_4, mg/m²/h	CO_2, mg/m²/h
15/08/2011	SE, 450 m	17:45	2	–0.09	42.6
15/08/2011	SE, 450 m	19:45	2	–0.006	41.2
15/08/2011	SE, 750 m	13:05	4.5	0.14	n.s.
15/08/2011	SE, 750 m	15:00	5	–0.21	146.4
15/08/2011	SE, 750 m	17:00	5	–0.04	91.3
15/08/2011	SE, 750 m	19:00	5	–0.06	169.7
15/08/2011	SE, 750 m	13:50	4.5		n.s.
15/08/2011	SE, 750 m	15:45	5	0.2	n.s.
15/08/2011	SE, 750 m	17:45	5	0.17	45.2
15/08/2011	SE, 750 m	19:45	5	0.05	49.1

Note: *n.s.* not significant values

Table 3 Results of measurements of the carbon dioxide and methane (average per day) in the district of Processing plant-2, August 2011 ($mg/m^2/h$)

Plot symbol	Ip	CH_4		CO_2	
		Mean	Standard deviation	Mean	Standard deviation
ch-NW-0	85	–0.17	0.24	85	66.7
ch-NW-500	57	–0.03	0.07	102	84.2
ch-NW-5000	13	0.08	0.14	283	343.4
ch-NW-0	85	0.03	0.11	248	251.0
ch-NW-360	75	0.43	0.57	468	179.5
ch-NW-500	57	0.06	0.10	147	107.7
ch-NW-5000	13	0.24	0.28	123	86.4
ch-SE-0	92	–0.19	0.19	86	42.6
ch-SE-450	80	0.20	0.16	55	25.6
ch-SE-750	76	–0.02	0.47	182	75.9
ch-SE-0	92	0.06	0.03	54	31.0
ch-SE-450	80	0.07	0.17	132	157.1
ch-SE-750	76	0.06	0.12	89	57.8

flow value was 158 mg $CO_2/m^2/h$. This value lies within the emission of carbon dioxide received for tundra ecosystems of Western Zemlya and Taimyr tundra (Zamolodchikov et al. 1997): from 87 to 169 mg $CO_2/m^2/h$. Similar to (Glagolev and Smagin 2006), the flow of methane was characterized by a low rate of emission, averaging 0.063 mg $CH_4/m^2/h$, which indicates the absence of significant sources of methane in the studied soils. Therefore, in conditions of the impacted zone Processing plant-2 is not marked changes in the biogeochemical cycle of carbon.

Acknowledgements The authors wish to thank Dr. Glagolev M.V. (Tomsk university) for help in field monitoring as well as "Gazprom Dobycha Yamburg" LLC for financial support of this study.

References

Bashkin, V. N., Arno, A. B., Arabsky, A. K., Barsukov, P. A., Priputina, I. V., & Galiulin, R. V. (2012). *Retrospective and forecast of geoecological situation on the gas condensate fields of the far north*. Moscow: Gazprom VNIIGAZ. 280pp.

Glagolev, M. V., & Smagin, A. B. (2006). Estimation of methane emission in bogs: from soil profile to region. *Reports on Environmental Soil Science, 3*(3), 75–115.

Heikkinen, E. P., Virtanen, T., Huttunen, J., Elsakov, V., & Martikainen, P. J. (2004). Carbon balance in East European tundra. *Global Biogeochemical Cycle, 18*, GB1023. doi:10.1029/2003GB002054.

Kutzbach, L., Wille, C., & Pfeiffer, E.-M. (2007). The exchange of carbon dioxide between wet arctic tundra and the atmosphere at the Lena River Delta, Northern Siberia. *Biogeosciences, 4*, 869–890.

Lopez de Gerenyu, V. O., Kurganova, I. N., Rozanova, L. N., & Kudeyarov, V. N. (2001). Annual flows of carbon dioxide from some soils of the southern taiga zone of Russia. *Eurasian Soil Science, 9*, 1045–1059.

Nakano, T., Ashahi, C., Inoue, G., & Fukuda, M. (2001). Measurements of methane and carbon dioxide in a birch forest in West Siberia after burning. In *Proceedings of Ninth Symposium on the Joint Siberian Permafrost Studies Between Japan and Russia in 2000* (pp. 145–149). Tsukuba: Isebu.

Nakano, T., Sawamoto, T., Morishita, T., Inoue, G., & Hatano, R. (2004). A comparison of regression methods for estimating soil-atmosphere diffusion gas fluxes by a closed-chamber technique. *Soil Biology and Biochemistry, 36*, 107–113.

Omelchenko, M. V. (1994). *Psychrophilic methanotroph and his companions*. The abstract of dissertation on competition of a scientific degree of candidate of biological sciences. Moscow: MSU Press, 24pp.

Sabrekov, A. F., Glagolev, M. V., Sleptsova, I. E., Bashkin, V. N., & Barsukov, P. A. (2011). Contribution of permafrost mounds in methane emission from tundra wetlands in West Siberia. *Environmental Dynamics and Global Climate Change, 2*(4), EDCCP0001.

Shnyrev, N. I., & Glagolev, M. V. (2007). Characteristic values of the fluxes of methane from wetlands in Western Siberia. In: *West Siberian Peatlands and Carbon Cycle: Past and Present. Proceedings of Second International Field Symposium* (pp. 144–146). Tomsk.

Zamolodchikov, D. G., Karelin, D. V., & Ivaschenko, A. I. (1997). Carbon balance of ecosystems of the tundra zone of Russia. In D. G. Zamolodchikov (Ed.), *Carbon in ecosystems. XV readings in commemoration of V.N. Sukachev* (pp. 99–121). Moscow: Nauka.

Specific Reaction of Biota to Environmental Pollution in Tundra Ecosystems

Vladimir N. Bashkin, Pavel A. Barsukov, and Anatoly K. Arabsky

Abstract This paper shows the specific reaction of biota to gas industry environmental pollution in tundra ecosystems, such as alteration of tree-ring size of Siberian larch, changes in biodiversity of plant components, and accumulation of biological elements (nitrogen and phosphorus) on biogeochemical barriers in plants in the impacted areas of facilities for gas production complex. On a basis of these researches, we can conclude that atmospheric nitrogen-containing pollutants have a significant fertilizing effect on tundra ecosystems that is manifested in the reliable increase in the content of nitrogen, directly and phosphorus, indirectly through the enhancement of biochemical processes in plants. It is established that both studied species of lichens (*Alectoria ochroleuca* and *Alectoria nigricans*), and dwarf birch leaves can be used as indicator species/plant organs when considering atmospheric pollution. Increasing concentration of nitrogen in the tissues of tundra plants presents the evidence of its effective absorption by plant community that is most likely to lead to increased productivity of tundra plant communities as a whole.

Keywords Tree-ring analyses • Accumulation of nitrogen and phosphorus in lichen • Changes in biodiversity of plant components • Gas industry impacted zone • Tundra ecosystems • Environmental pollution

V.N. Bashkin (✉)
Institute of Physicochemical and Biological Problems of Soil Sciences of Russian Academy of Sciences, Pushchino, Moscow Region 142290, Russian Federation

Institute of Natural Gases and Gas Technologies—Gazprom VNIIGAZ LLC, Razvilka, Moscow Region 142719, Russian Federation
e-mail: bashkin@issp.serpukhov.su

P.A. Barsukov
Institute of Soil Science and Agrochemistry of Siberian Branch of Russian Academy of Sciences, Novosibirsk 630099, Russian Federation

A.K. Arabsky
Gazprom Dobycha Yamburg LLC,
Novy Urengoy, Yamalo-Nenets Autonomous District 629300, Russian Federation

V.N. Bashkin (ed.), *Biogeochemical Technologies for Managing Pollution in Polar Ecosystems*, Environmental Pollution 26, DOI 10.1007/978-3-319-41805-6_6

1 Introduction

Vegetative component of terrestrial ecosystems largely determines their self-assembly and structural ordering. It is inherent in the biotic component of the feedback system, which determines the sustainable development of ecosystems. Especially the role of vegetation in the self-organization and stable existence of ecosystems is important in the extreme climate areas, such as tundra and forest tundra. The amplification of anthropogenic impact requires careful analysis of vegetation for predicting the stability of natural systems.

The territory of the Taz peninsula, where the main enterprises of LLC "Gazprom Dobycha Yamburg" are placed, is an area of very intense ecological situation. Currently there is an intensive development of the peninsula associated with the development of hydrocarbon fields of gas and condensate. These field developments are accompanied by disturbances of the vegetation cover, the activation of exogenous processes. This predetermines the need to consider the phytocenotic and floristic diversity with a selection of objects requiring special attention and protection.

In accordance with the zonal division of the Western Siberia territory of Taz peninsula occupies tundra and forest-tundra (boreal-subarctic) zone. The vegetation is a complex mix of tundra, bogs, and larch forests.

Vegetation cover of forest-tundra zones is defined primarily by the distribution of light larch forests that in Western Siberia are distributed from the lower Ob river to the Yenisei river. Common features of these forests can be considered as thinning of the forest stand and the extraordinary diversity and heterogeneity of the lower tiers, reflected in the formation of various forms of heterogeneous composition. All light forests by purpose classified as climate system group I (Chertovsky et al. 1987), as found in the path of the prevailing winds of the Northern directions. They are located as islands or stripes. Stands have simple structure: sparse low density and the density of crowns.

The dominant (often the only) form of trees is Siberian larch (*Larix sibirica*), which reaches a height of 8–10 m, being erect. Age, according to dendrochronological studies, averaging 100–150 years, in individual instances—400–450 years. The distance between trees is from 3 to 20 m. The undergrowth is between 0.3 and 6 m, in good condition.

Despite the subordinate role of forest communities in the landscape structure of the territory, these areas are typically occupied by the oil and gas complex infrastructure. Forests on drained locations are most affected during the construction and development of deposits: more than 50 % of the total area of disturbed lands are former forests (Kozin and Maryinskich 1999).

Therefore, it is necessary to consider the bioindicators determining the specific reactions of biota to environmental pollution in the impact areas of the oil and gas industry.

2 Tree-Ring Analysis of Siberian Larch

Technological and economic human impact on the environment brings about dangerous changes in ecological systems, landscapes and extensive natural systems. Determination of changes in the composition of ecological systems, ecosystems, natural systems and their productivity (environmental monitoring) has no uniform system of accounting values. The degree of disruption of natural systems, ecosystems, individual components of the biosphere component is determined by comparing them on a number of indexes and their characteristics from undisturbed ecosystems, the dynamics of identifiable changes. Questions to determine the extent and nature of the impact on the forest's natural processes and anthropogenic factors can be solved by dendrochronological methods.

The dendrochronology is based on a good "memory" of the trees that form forest ecosystems, which in structure, chemical composition and size of annual growth rings clearly record all changes that occur within the ecosystem, and external conditions that determine their development. Dendrochronology refers to the integrated method of research, able with sufficient reliability and temporal precision to explain the past development of the main component of the forest ecosystem—a forest stand. Unlike conventional monitoring methods, consisting in direct observation of one or another influence, dendrochronology allows us to recover many of the changes in forest communities over several decades and even centuries.

Dendrochronological methods are widely used in the study of ecosystems, displacement of natural zones and boundaries, when determining the extent of human impact on forest ecosystems. Researchers work on the development of dendrochronological method and its use to reconstruct and identify patterns of many natural and anthropogenic processes affecting the change of the annual increment of woody plants (Shiyatov and Comyn 1986).

The growth of individual trees and forest stands in general, the most universal and generalized characteristic of their condition. When assessing the impact of anthropogenic factors on forest ecosystems it is impossible to do without the use of this feature to analyze the situation. Along with the study of changes in the average growth rate during the analyzed time interval it is also advisable to study the mode of oscillation that provides valuable information about the operation of stands in the area of influence of anthropogenic factors (Alekseev 1990). To date, studies of dendrochronologia cover a wide range of problems associated with human influence on forest ecosystems.

On the territory of LLC "Gazprom Dobycha Yamburg" have been already carried out studies using dendrological method, with an additional analysis of the different age of the annual rings on the isotopic composition of carbon. This research is based on the ability of plants to selectively assimilate isotopically light molecules $^{12}CO_2$ compared to $^{13}CO_2$. The ^{13}C deficit increase is associated with increasing contribution of the nonequilibrium processes of diffusion of CO_2 and the inhibition of activity of the system of reversible (quasi-equilibrium) metabolic pathways under the influence of adverse environmental conditions. The results indicate that the nature immediately reacts to the appearance of man, but on condition of strict compliance with environmental legislation the nature quickly calms down, coming to a new steady state without degradation (Arabskiy et al. 2009).

To explore the possibility of using dendrochronological analysis in the evaluation of the contamination by the pollutants we studied the growth of annual rings of Siberian larch (*Larix Sibirica*), which grows at a distance of 1.3 km in the direction Northeast from the processing plant-6. The geographical coordinates of the sampling of wood samples: 67.9863 N, 75.9845 E. Samples were taken in fourfold repetition with four trunks of Siberian larch, respectively.

The annual growth of the larch varied greatly by year, reflecting the changing weather conditions of a particular year (temperature, moisture conditions, flood events) (Fig. 1). The trend line indicates a reduction in the rate of growth of wood with increasing age of the tree, which in general is characteristic of this tree species. Commissioning of the processing plant-6 in an explicit form did not affect the change in growth of annual rings.

However, statistical analysis of the thickness of annual rings by the method of principal components allowed us to detect clear variations in the pattern of change of the line describing the dependence of component 1 from component 2 in 1988: there is a sharp line deviation from the normal spiral shape oriented clockwise (Fig. 2). Seven years before (in 1981) observed the same change of stroke lines. In a message to employees LLC "Gazprom Dobycha Yamburg" in this year has begun and actively carried out exploration work on the territory of the future construction of the processing plant-6. For all other years the growth of the studied specimens of Siberian larch (1914–2011) such a drastic change of the shape of the

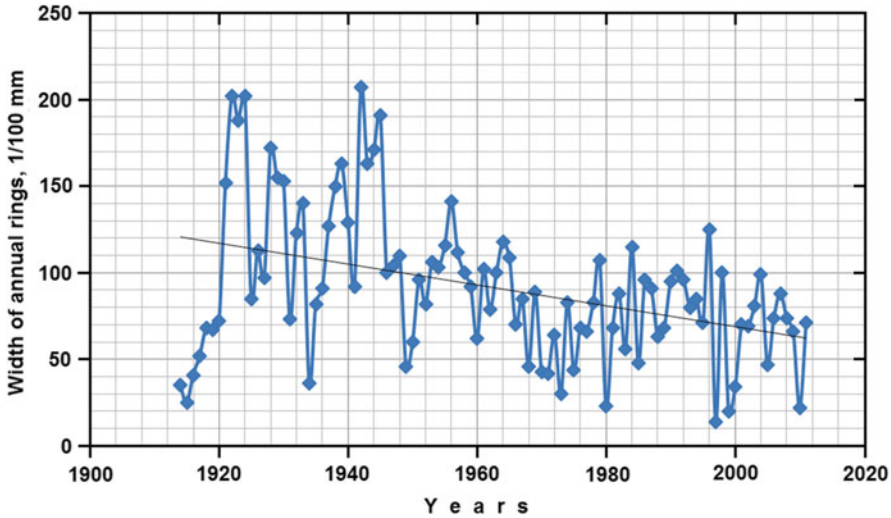


Fig. 1 Change of annual growth of Siberian larch (average of four replications): y-axis—width of annual rings (1/100 mm), x-axis—years

Table 1 Change the concentration of carbon, hydrogen and nitrogen in annual rings of different years

	Element content, %		
Years	C	H	N
1978–1987	47.84	6.29	0.110
1983–1993	48.28	6.28	0.140
1994–2002	47.68	6.12	0.167
2003–2011	48.45	6.22	0.219

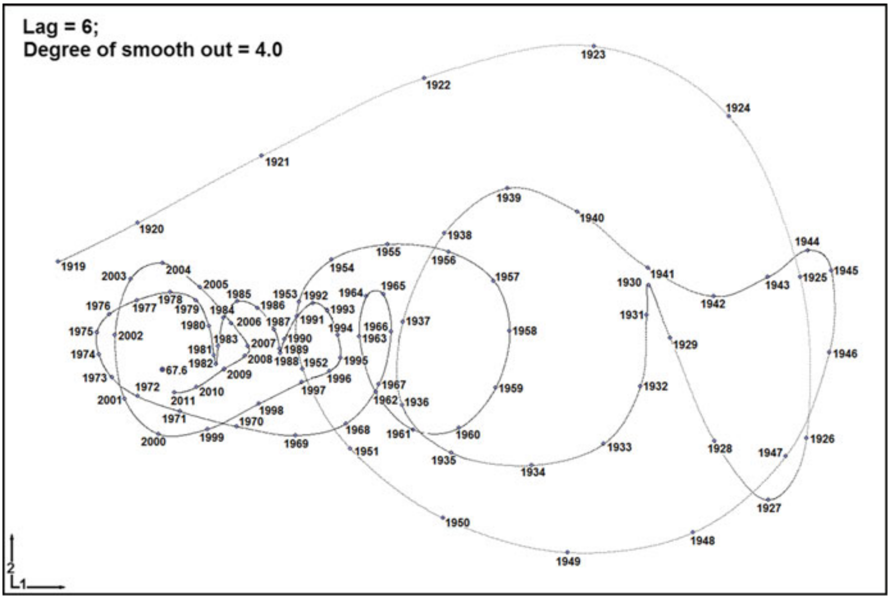


Fig. 2 Statistical data processing dendrochronological analysis by principal component method

curve (deviation from regular spiral, twisting clockwise) was in 1930, however, the deviation had a different ("opposite") form in comparison with variations in 1981 and 1988, which we presumably associated with anthropogenic impacts: construction/survey work near UCPG 6 and the beginning of atmospheric pollution in 1981 and 1988, respectively.

Analysis of nitrogen content in the annual rings in the frames, 2011–2003, 2002–1994 years, 1993–1983, and 1987–1978, showed a clear trend of increasing nitrogen content in the annual rings with time (Table 1). This clearly indicates efficient absorption of nitrogen-containing pollutants by Siberian larch. Our data are in good agreement with the literature data about the responsiveness of tree species (increase in the nitrogen concentration in annual rings) on the increase of air pollution (Cherubini et al. 2011).

This is also confirmed by the statistical analysis (Fig. 2).

3 Changes in Biodiversity of Plant Components in the Gas Industry Impacted Area

At present the most objective way of assessing the biodiversity of plant components of ecosystems at a sufficiently large area is to build an electronic map of vegetation, derived using different methods of decoding space images of high resolution. As a plot for the interpretation we have chosen a rectangular plot near the processing plant-2, oriented to the cardinal Northwest to Southeast according to the wind rose in the area of Yamburg. During our interpretation were used the data of geobotanical descriptions of plant communities (Bashkin et al. 2012).

As cartographic basis was taken a satellite high-resolution image GeoEye with resolution of 0.6 m per pixel. Thematic interpretation of the image was carried out in the program Timan 7.2 based on pre-trained neural network. The results of the direct interpretation of the image show a very high level of complexity and diversity of vegetation cover, making the map almost unreadable and difficult to understand. For the purposes of the generalization of an image in ENVI 3.7 program the original image resolution was coarse up to 10 m per pixel by the method of aggregating neighboring values. Generalized image again was subjected to semi-automatic classification in the Timan 7.2. The interpretation of the obtained image with the previously described and georeferenced sample plots allowed us to identify eight confident and distinguishable in the picture legend items (Fig. 3). First of all, it is well highlighted various anthropogenic structures and disturbances associated with damage to soil and vegetation cover (bright red color on the map). This includes both areal and linear objects. Drew the attention of a large contour outdoor sand pit, partially flooded with water. Small bulges erosion of natural origin in the composition of the contours medalonnye tundra also relate to this element of the legend. Well contours medalonnye tundra observes in drained habitats (orange color).

Communities of zonal tundra in satellite image are almost indistinguishable from the communities on the surface of the frozen polygon-palsa mires. In both cases the soil surface is covered with a thick carpet of lichen with sparse shrub layer on top of it. By location in the landscape, these communities are also often the same. So on the map they are shown by a single contour of zonal tundra (grey).

Shrub communities along the valleys of streams (dwarf birch) (turquoise color) to the horizontal projection of the picture present small circuits interspersed with herbaceous hygrophilous vegetation. The location of the communities on the slopes leads to underestimation of their area in the picture.

Wet tundra (dark green) occurs often in the form of many small contours on the background of zonal communities.

Sedge-cotton grass bogs (khaki) and marshy meadows (light green color) as a rule, form complex systems made of small circuits, often associated with open water bodies (dark blue) or manmade objects.

On the final map of vegetation cover of the surroundings of the processing plant-2 is clearly visible the strong flooding of the territory as a whole with the abundance of lakes of various shapes and sizes, as well as smaller watercourses. In

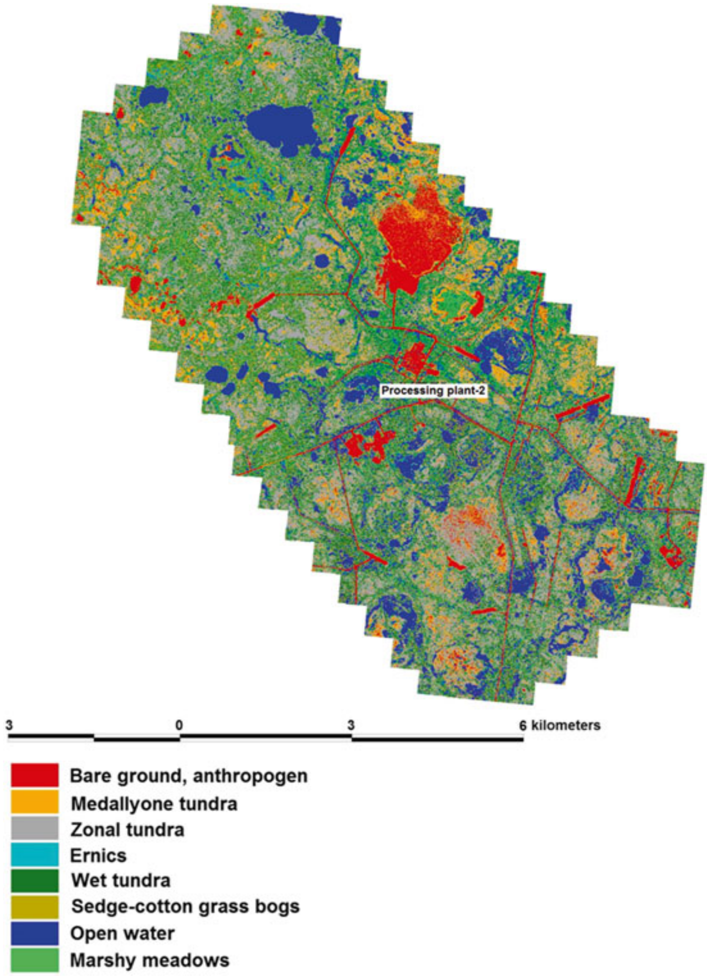


Fig. 3 Digital map of the vegetation in the vicinity of the grid system-2 on the basis of decoding space images GeoEye 0.6 m/pixel with desensitization to 10 m/pixel

general, from the Southeast to Northwest the overall drainability increases. Vegetation cover, despite the performed generalization, maintains a complex character. The distribution of vegetation complexes is mainly subordinated to lacustrine basins, modern and ancient (khasyrey), with the formation of large, up to 1.5–2 km in diameter, roundish in general outline integrated circuits with a logical succession changes within each of them.

It is apparent the attraction of hygrophilous vegetation and, especially, marshy meadows to anthropogenic objects and to the processing plant-2 (the distribution of the contours of the green color). However, as noted above, we are inclined to consider it as a reaction to the disturbance of habitats during construction, and not as a consequence of the activities of this unit.

Summing up this work, it can be argued that the vegetation of southern tundra in Western Siberia within the Yamburg gas condensate field on a qualitative level (biodiversity of plant components of ecosystems) is not found significant influence of the modern technological activities of the processing plant-2.

4 Accumulation of Biophilic Elements (Nitrogen and Phosphorus) on Biogeochemical Barriers in Plants

In the literature there is evidence that atmospheric pollutants containing nitrogen and phosphorus, can play the role of fertilizers in tundra ecosystems, increasing the productivity of phytocenoses, and the concentration of nitrogen and phosphorus in plant tissues (Bashkin et al. 2012). Moreover, a significant effect is observed even at low doses of these elements. To investigate this question the changing of content of nitrogen and phosphorus on a broader gradient of the contamination level of the territory were considered. The received data included the results of determining the content of nitrogen and phosphorus in plants:

- lichen *Alectoria ochroleuca*;
- lichen *Alectoria nigricans*;
- dwarf birch, leaves;
- dwarf birch, branches.

Samples of plants for analysis were selected from ten habitats, differing by integral load index of atmospheric pollutants equal to 0.2, 0.4, 8, 11, 25, 34, 86, 91, 95, and 96. Selection of particular points of plant samples is due to the obligatory presence in the place of the lichens *Alectoria nigricans*, which, in comparison with the lichen *Alectoria ochroleuca*, in less widespread on the territory of LLC “Gazprom Dobycha Yamburg”. Simultaneously with the sampling of these two species of lichen were selected samples of the leaves and branches of dwarf birch.

The results are presented in Table 2 and Figs. 4, 5, 6, 7, 8, 9. Reliable direct correlation was obtained between the content of the investigated biophilic element (nitrogen or phosphorus) and a load index of atmospheric pollutants (*Ip*) for both species of lichens and dwarf birch leaves. The concentration of nitrogen and phosphorus in the branches of dwarf birch did not correlate with levels of pollution.

Universal form of the regression relationship of biological concentration of elements in plants from the Ip is an exponential equation of the form $C_{NP} = A * Exp(B * Ip)$ where C_{NP} is the concentration of nitrogen or phosphorus in plant tissues.

Thus, we can conclude that atmospheric nitrogen-containing pollutants have a significant fertilizing effect on tundra ecosystems that is manifested in the reliable increase in the content of nitrogen, directly and phosphorus, indirectly through the enhancement of biochemical processes in plants. It is established that both studied species of lichens (*Alectoria ochroleuca* and *Alectoria nigricans*), and dwarf birch leaves can be used as indicator species/plant organs during atmospheric pollution. Increasing concentration of

Table 2 Results of nonlinear correlation and regression analyses of the relationship of the concentration of nitrogen and phosphorus in plants from the magnitude of the load index of atmospheric pollutants (Ip) calculated in accordance with (Bashkin, Galiulin, Barsukov, Arabsky, Gas industry impacts on natural ecosystems)

Species/plant organ	Element	Number of samples	Coefficients		Non-linear regression coefficients	
			Correlation	Determination	A	B
Lichen *Alectoria ochroleuca*	N	19	0.85	0.72	0.293	0.0031
	P	19	0.69	0.48	0.014	0.0066
Lichen *Alectoria nigricans*	N	12	0.91	0.83	0.241	0.0043
	P	12	0.90	0.81	0.012	0.0075
Dwarf birch (*Betula nana*), leaves	N	19	0.82	0.67	1.228	0.0039
	P	19	0.80	0.64	0.120	0.0100
Draft birch (*Betula nana*), branches	N	19	n.d.	n.s.	n.d.	n.d.
	P	19	n.s.	n.s.	n.d.	n.d.

Note: *n.d.* not determined, *n.s.* not significant, all other coefficients of correlation and determination are true 5 % level of significance

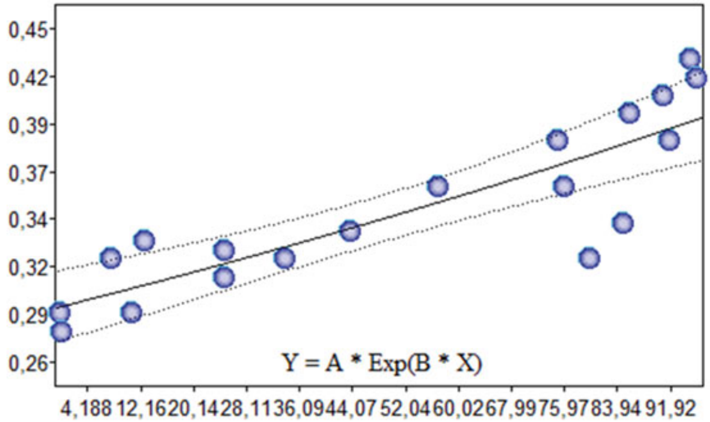


Fig. 4 Dependence of nitrogen concentration (%) in the lichen *Alectoria ochroleuca* (y-axis) against load index of atmospheric pollutants (x-axis)

nitrogen in the tissues of tundra plants presents an evidence of its effective absorption by plant community that is most likely to lead to increased productivity of tundra plant communities as a whole. Rather increasing its absorption in the nitrogen input causes the increase in the concentration of phosphorus in the tissues.

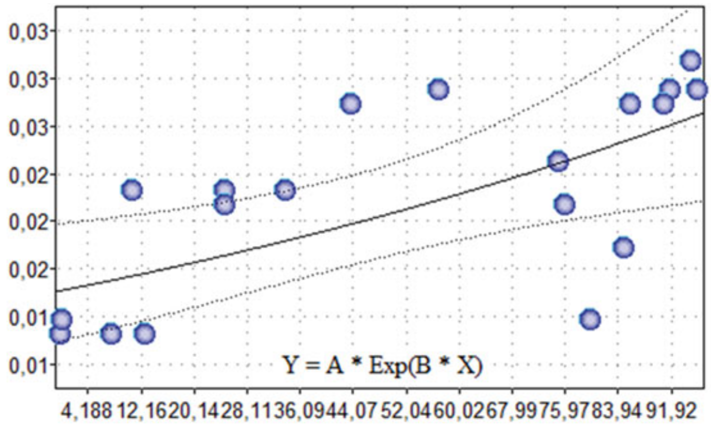


Fig. 5 Dependence of phosphorus concentration (%) in the lichen *Alectoria ochroleuca* (y-axis) against load index of atmospheric pollutants (x-axis)

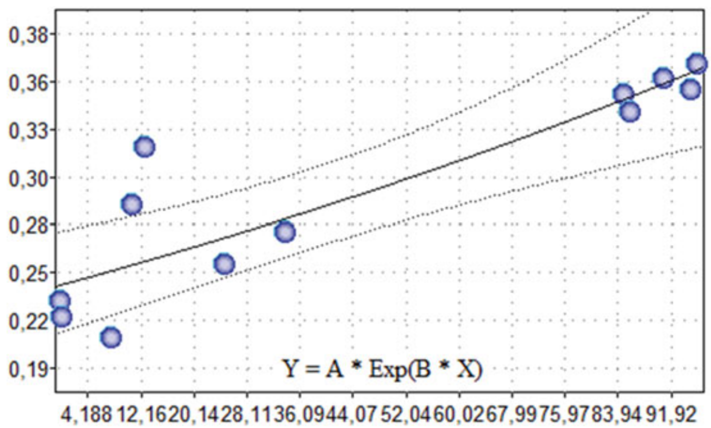


Fig. 6 Dependence of nitrogen concentration (%) in the lichen *Alectoria nigricans* (y-axis) against load index of atmospheric pollutants (x-axis)

5 Accumulation of Biological Elements (Nitrogen and Phosphorus) on Biogeochemical Barriers in the Soil

To clarify the influence of atmospheric pollution on the content of biophilic elements in the soil were selected soil samples from the upper horizons of soils near the various processing plants. On each of the seven points corresponding to the load indices of atmospheric pollutants 0.4, 8, 25, 34, 86, 91 and 95, three soil samples were selected. Thus, the total number of samples was equal to 21. In all cases, soil samples were selected from two close types of soil: peat-gleezem permafrost and peat-criozem cleyely crioturbated. The depth of the upper horizon was, on average, equal to 9.3 cm, standard deviation±3.34 cm. Loss on ignition of samples were equal to 74.1%, standard deviation±13.95%.

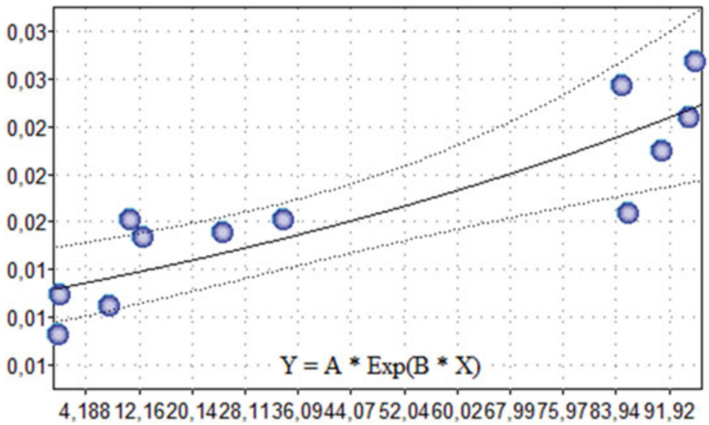


Fig. 7 Dependence of phosphorus concentration (%) in the lichen *Alectoria nigricans* (y-axis) against load index of atmospheric pollutants (x-axis)

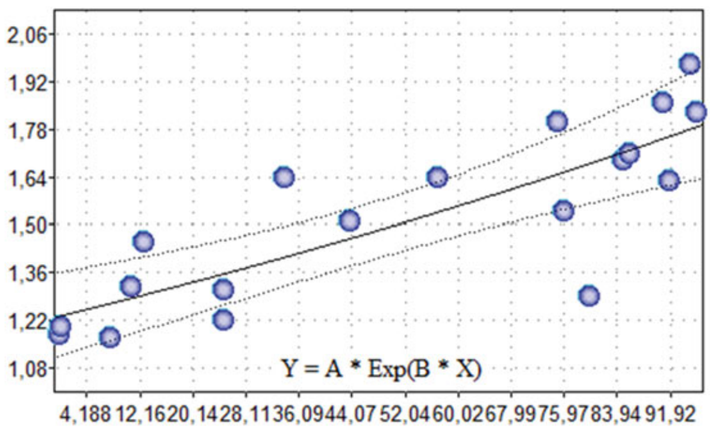


Fig. 8 Dependence of nitrogen concentration (%) in leaves of dwarf birch (y-axis) from the load index of atmospheric pollutants (x-axis)

Selected soil samples were analyzed for contents of total nitrogen and carbon. The results of the correlation and regression analysis (linear and nonlinear) showed that reliable dependence between the content of both nitrogen and phosphorus, on the one hand, and a load index of pollutants, on the other hand, has not been received. Most likely, the main reason is the high heterogeneity of the soil cover and, consequently, natural differences in the content of nitrogen and phosphorus in the soil. Another cause can be exogenous transformation processes of nitrogen and phosphorus entering the soil with atmospheric pollutants. This leads to a redistribution of elements-pollutants in the soil profile. In addition, given the complex micro- and nano-topography of tundra ecosystems probably is the horizontal migration of chemical elements. Given that we study zonal ecosystems/soils, i.e. samples were

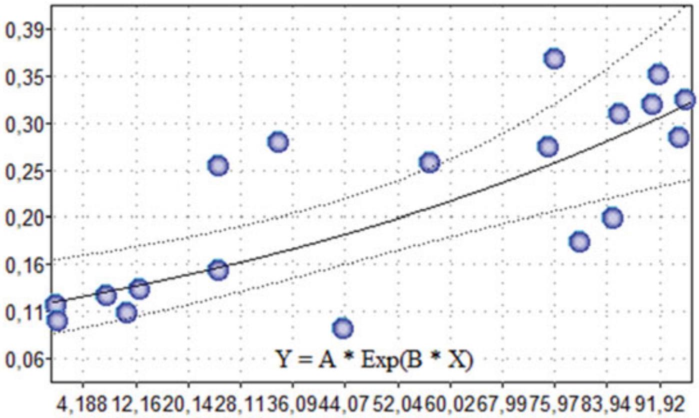


Fig. 9 Dependence of phosphorus concentration (%) in leaves of dwarf birch (y-axis) from the load index of atmospheric pollutants (x-axis)

taken in the higher relief position, it is likely the partial runoff of the nitrogen-, phosphorus- and carbon-containing pollutants from surface soils of zonal ecosystems in subordinate positions of relief. Most likely this occurs during the snowmelt period and during the period of falling liquid precipitation (Bashkin 2014).

6 Conclusions

Thus, on of the best ways for assessing environmental pollution is selection of bioindicators We show the specific reaction of biota to environmental pollution in tundra ecosystems, such as alteration of tree-ring size of Siberian larch, changes in biodiversity of plant components in the impact areas of facilities for gas production complex, and accumulation of biological elements (nitrogen and phosphorus) on biogeochemical barriers in plants and, in less degree, in soils. On a basis of these researches, we can conclude that atmospheric nitrogen-containing pollutants have a significant fertilizing effect on tundra ecosystems. It is established that both studied species of lichens (*Alectoria ochroleuca* and *Alectoria nigricans*), and dwarf birch leaves can be used as indicator species/plant organs under atmospheric pollution.

References

Alekseev, V. A. (1990). *Forest ecosystems and atmospheric pollution*. Leningrad: Nauka. 200pp.

Arabskiy, A., Andreev, O., Salikhov, Z., Makluk, O., Jarygin, G., Gabuda, S., et al. (2009). High technologies of environmental management on gas fields of Gazprom Dobycha Yamburg LLC. In: *24th World Gas Conference Proceedings* (pp. 24–25). Buenos Aires, Argentina: IGU.

Bashkin, V. N., Arno, A. B., Arabsky, A. K., Barsukov, P. A., Priputina, I. V., & Galiulin, R. V. (2012). *Retrospective and forecast of geoecological situation on the gas condensate fields of the far north*. Moscow: Gazprom VNIIGAZ. 280pp.

Bashkin, V. N. (2014). *Biogeochemistry of polar ecosystems in gas industry impacted zones*. Moscow: Gazprom VNIIGAZ. 302pp.

Cherubini, P., Battipaglia, G., Siegwolf, R., Saurer, M., & Bovio, G. (2011). Tree-ring growth and stable isotopes (13 C and 15 N) detect effects of wildfires on tree physiological processes in Pinus sylvestris L. *Trees, 25*(4), 627–636.

Chertovsky, V. G., Semenov, B. A., & Tsvetkov, V. F. (1987). *Pretundra forests*. Moscow: Agropromizdat. 168pp.

Kozin, V. V., & Maryinskich, L. M. (1999). Forest ecosystems in landscape structure of the Urengoy oil, gas and condensate field. *Tyumen State University News, 3*, 115–119.

Shiyatov, E. G., & Comyn, N. N. (1986). *Dendrochronology and dendroclimatology*. Novosibirsk: Nauka. 213pp.

Biota Monitoring in the Impacted Zones of Oil and Gas Industry in the Arctic Region

Olga P. Trubitsina

Abstract The article focuses on biota monitoring in the impacted zones of oil and gas industry in the Arctic region as an important part of the ecological monitoring system. The relevant main tasks and methodological principles are noted. The article content provides the valuable information, which should be considered in the development and implementation of biota monitoring in the Arctic region. Finally, the need to use these information aspects together with scientific data from different countries is emphasized. It is related to the fact that the longer periods of time are required to establish baseline monitoring conditions because of the high degree of uncertainty in measurements of environmental components and in predicting impacts in the Arctic.

Keywords Arctic region • Biota monitoring • Ecological monitoring • Oil and gas industry

1 Introduction

The activity in the petroleum and natural gas industry in the Arctic Zone of the Russian Federation (AZRF) has been on the increase for the past several years and the geo-environmental risks (GER) have been growing accordingly. In comparison to many other parts of Russia, the Russian Arctic is considered to be a relatively pristine area. However, "contamination and other negative effects in the AZRF" result in the formation of "hot spots" and "impact areas" characterized by a high level of chemical contamination of the environment and transformation of the natural geochemical background, degradation of marine life, vegetation, soils, uncontrolled development of erosion, cryogenesis, formation of sinkholes across vast areas, introduction of contaminants to food chains, high disease rates among the population, air being polluted with strontium compounds, heavy metals (particularly mercury), petroleum products, etc. (Diagnostic Analysis … 2011).

O.P. Trubitsina (✉)
Northern (Arctic) Federal University, North Dvina Bank, 17,
Arkhangelsk 163002, Russian Federation
e-mail: test79@yandex.ru

V.N. Bashkin (ed.), *Biogeochemical Technologies for Managing Pollution in Polar Ecosystems*, Environmental Pollution 26, DOI 10.1007/978-3-319-41805-6_7

Expansion of oil and gas development projects, particularly offshore, can aggravate this situation. According to the strategic AZRF Environment Action Program (Strategic Action Program … 2009), "… the oil and gas industry activities in the Arctic Zone of the Russian Federation (AZRF) which have been on the rise for the last decade and the anticipated offshore development activities in the Barents and other Arctic seas put the environment at risk of degradation growing from local scale to one that spans the entire region. At present, the amount of crude oil that comes directly to the marine environment, fresh waters and land in the coastal areas of the AZRF is limited and not considered to be a factor significantly affecting the overall environmental situation in the region. The hazard of marine environment pollution with oil is related to the plans for offshore oil production in Russia."

Monitoring of changes in biogeochemical parameters in the terrestrial and marine ecosystems in the impacted zones of oil and gas industry is one of the objectives of risk management, which deals with expansion of oil and gas production in the Polar Regions (Bashkin et al. 2015).

It is known that polar zone ecosystems are unstable at man-induced influences, and it takes a long time for them to restore after infringements, especially at oil and gas production. Therefore, organization of biota monitoring system in areas of industrial complexes is of great significance in the general system of industrial ecological monitoring. Its efficiency will depend on methodological balancing, methodical provisions and legible structural organization (Trubitsina and Sidorova 2013).

2 Biota Monitoring in the Impacted Zones of Oil and Gas Industry as a Part of Ecological Monitoring System

We define ecological monitoring as a system of regular monitoring of natural environments, which allows tracing changes to the structure and function of ecosystems, occurring inter alia under the influence of man-induced activities. Ecological monitoring is used in impact assessment, forecasting of ecological conditions of human and biological habitats, and for the provision of updated environment preservation guidelines.

According to Federal Law of Russia (Federal Law … 2002) 'environment monitoring (ecological monitoring) is a complex system of observations over environmental conditions, assessment and forecast of changes in environmental conditions under the influence of natural and man-induced factors'. The general concept of environmental monitoring in the Russian Arctic coastal regions is considered on the base of Strategic Action Program for Protection of the Russian Arctic Environment and international cooperation.

The environmental conditions in the Arctic make monitoring a demanding task requiring careful planning. Through monitoring, the accuracy of environmental impact predictions is also assessed. A good monitoring program will provide adequate information to measure environmental change and assess the effectiveness of procedures employed to mitigate adverse impacts. This information should be the basis for modifying the activity or mitigation measures. If necessary, those responsible for the activity are required to further reduce environmental effects, protect resources, or improve the efficiency of the activity (Arctic Environment Protection Strategy 1997).

Ecological monitoring allows assessing the condition of ecosystems and the dynamics of their changes, to create pre-requisites for development of measures to minimize impacts on the environment, and, in the long term, to work out most efficient nature protection activities. At that, attention should be focused on preservation of the water bio-resources, which are of great importance both for existence of the whole water body ecosystem and for fishery interests.

Main biota monitoring tasks are gathering information about biota condition in industrial construction areas, defining threshold effects of existing and designed facilities on certain components of ecosystems and their dynamics, defining especially vulnerable zones, defining main directions of pollutants migration by biotic components, creating information database for developing short-term (2 years) and long-term (5–8 years) forecasts of potential impacts, and also operative forecasts in case of potential accidents.

Monitoring system will be based on standard methodological principles: target-oriented monitoring, consistency, integrity, periodicity, and unification.

From all variety of effects influencing the biota at placing marine pipelines, we can distinguish two groups of factors which differ by the nature of their effects on natural systems: operation of mechanisms and processes connected thereof (increased water turbidity due to high concentrations of a suspended bottom sludge at excavation of trenches in shallow areas), and hydrocarbon effects.

3 The Aspects to be Considered in the Development and Implementation of Biota Monitoring in the Arctic Region

Any effects of hydrocarbons on live organisms (biosorption, nutrition, etc.) trigger a very complicated chain of biochemical transformations involving ferment systems. The latter can considerably change the chemical structure of initial oil compounds by transforming them into metabolites. Such transformations occur on the background of biosynthesis and biochemical dynamics of others natural hydrocarbons in bodies and tissues of live organisms. It is obvious that identification and definition of oil hydrocarbons in biological tests is a more difficult analytical problem as compared to tests of water- and bottom sludge samples. This is one of the reasons of extremely high scattering of available oil hydrocarbons data (primarily, polynuclear aromatic hydrocarbons) in marine organisms of Arctic regions (Matishov et al. 1997, 2004; Patin 2009a, b; AMAP 1998; OSPAR 2000). However, there is a positive correlation between concentrations of oil hydrocarbons in pelagian and bottom organisms and their concentrations in water and bottom sludge, correspondingly. Concentration of polynuclear aromatic hydrocarbons (PAH) in aquatic organisms is, at least, on two to three times higher than relevant values for water. Similar relationships for benthic life and soils are significantly lower, and sometimes close to ‘one’.

Concentrations of PAH and other oil components in live organisms is defined, ultimately, not only by their concentration in the environment, but also by the relationship between the rate of their entering into the organism, intensity of fermented decomposition in bodies and tissues, and the clearance rate (Patin 2009a, b).

Benthic vertebrates (especially, bivalve mollusks), due to less developed, as compared to fishes, fermented and metabolic systems, and also due to their high filtration activity and bottom habitat, possess, as a rule, a higher ability for oil compounds accumulation. For this reason, attached and inactive benthic organisms (normally, mussels and oysters) are often used, along with bottom sludge, as standard objects for oil pollutions monitoring in marine environments (AMAP 1998; OSPAR 2000). In the shallow coastal zone, the most long-term and steady reorganizations are observed in bottom vertebrates’ populations. Their restoration may take several years. Data about accumulation of PAH in mussels and oysters are used as benchmark indicators at making decisions on closing or resuming fishing activities in oil-spill cases (Patin 2001; NAS 2003).

Distribution of oil hydrocarbons in marine organisms is characterized by extreme heterogeneity and development of increased concentrations in bodies and tissues contacting with water, and also in systems of accumulation (deposition), metabolic decomposition (detoxication) and clearing (excretion). Due to lipophilic properties of oil hydrocarbons, they also tend to accumulate in bodies and tissues with increased concentrations of fats and lipids. Numerous publications indicate that highest levels of PAH concentrations in fishes are mostly found in their liver and bile, and also in gills, gonads, fat depots and tissues (Patin 2009a, b) more often. In mollusks and others vertebrates, PAH are mostly accumulated in their digestive and reproductive organs bodies, which are rich with lipids. There are also cases when oil lumps and compounds were found in stomachs and digestive tracks of sea fishes, vertebrates and mammals (Baker et al. 1990).

Indicated for some toxic agents (mainly, for heavy metals and chlorinated derivative) phenomena of increasing their concentrations in marine organisms with the increase of trophic level (‘food chain effect’), most likely, does not affect distributions of main oil hydrocarbons in marine populations. At the same time, we should not exclude a possibility of similar effects for high-molecular and steady PAH of benz(a)pyrene, which stability and lipophilicity can lead to their accumulation in top-level organisms of marine trophic pyramids (Patin 2009a, b).

Phytoplankton. The main source of danger is changes in physical and chemical parameters of environments in the course of oil and gas fields’ exploration and development. At execution of works, sea environments and, first of all, biotas will be affected by the following processes:

– discharges of drilling mud and raising bottom sludge at installation of underwater equipment (increasing water turbidity);

- potential leakages of fuel and lubricants, gas, gas condensate, methanol, and drilling liquids causing chemical water pollutions;
- household wastewater discharges;
- diverse effects of hydrocarbons on aquatic organisms;
- local temperature increases due to putting into operation rig cooling systems and power-engineering installations.

Furthermore, there is impossible to exclude the probability of emergencies during production and transport of HC. In this case, the greatest ecological hazard will be represented by large-scale spills of oil, gas condensate, methanol, mono-ethylene glycol and LNG (Scientific-Methodical Approaches … 1997).

Planktonic populations will be influenced by the following factors:

1. water eutrophication due to household waste discharges;
2. pollution of aquatic areas with petroleum products;
3. discharges of soil to sea at execution of drilling works;
4. water pollutions with drilling mud;
5. water intake.

At monitoring of sea biota, it is important to define the vegetative period of phytoplankton by revealing the active vegetation period, which is period of maximum risk for phytoplankton populations.

Zooplankton is the most sensitive to negative man-induced effects at coastal areas. So, the greatest negative effect for populations will occur during the periods of most active reproduction processes, and main zooplankton biomass formation. Accordingly, spring and summer periods are characterized by hyper-sensibility of zooplankton aquatic organisms to man-induced impacts.

For *macrophytobenthos*, of special risk are littoral and sub-littoral zones.

For *zoobenthos*, the coastal area inhabited by rare, protected economically valuable species is the main zone of risk.

Coastal areas inhabited by rare, protected, economically valuable species also become zones of greater sensitivity during emergency situations. This is where considerable bio-resources of bottom vertebrates are concentrated. Furthermore, these coastal areas are the main zones for reproduction, subsidence and habitat for young aquatic organisms of most species, including economically valuable commercial species, i.e., king crabs, northern shrimps, mussels, and scallops. King crab populations depend on coastal areas for spawning and breeding of young species, and their modification (epifauna destruction as a result of sea-bottom or other works in the coastal zone) is disastrous for adult life populations.

For *ichthyofauna*, the coastal area is also a zone of special importance and risk as main reproduction places of local and migrating fishes. Here belong most spawning areas of bottom fishes. These areas will be most vulnerable at emergencies.

Birds and *mammals*, among all sea biota, groups suffer mostly from oil spills. Ecological consequences of oil spills in Arctic regions are deteriorated by existing snow/ice covers 'which accumulate pollutants over a comparatively long period of time' (Trubitsina 2015). Ice, in such cases, serves as accumulator and carrier of spilled oil in Arctic regions, thus promoting its long stay in the sea and transfer on large distances from the spill place. In spring, when ice starts melting, oil comes to the surface of small open water areas. In these areas birds and mammals at this time of the year are normally concentrating, and direct contact with oil film can be especially disastrous. The priority protection areas in such situations should be gulfs, bays, river mouths, coastal lowlands, and shallow waters, especially if inhabited by rare or vanishing species.

Exploration of oil and gas fields is connected with the following man-induced environmental impacts:

- Interference into ground deposits and benthic organisms' populations by drill string penetration into sea bottom;
- Effects of nontoxic drilling mud on biota, including increase of water turbidity in the area of drilling platforms;
- Water pollutions with petrohydrocarbons through discharges from industrial facilities and emergency oil blowouts when drilling productive formations (Matishov et al. 2001).

As criteria for biota ecological conditions, structural and functional indicators characterizing a condition of vegetation and the animal populations shall be used. Among these, we should point out such indicators as changes in specific structure of phyto- and zoocenoses, reduction of species variety in zoocenoses, reduction of the main population's area, changes in density (number) of indicator species populations, reduction of projective coverage and vegetation productivity.

Important functions of biological monitoring are: development of early warning response systems, diagnostics and forecasting of changes in biological populations (Burdin 1985). At development of early warning response systems, it will be necessary to choose suitable organisms, which will accurately reflect biotas response to men-induced changes of the environment.

At bio-monitoring organization, a system of natural environment integrated control stations should be created.

Monitoring criteria:

1. Assessment of changes in species structure and quantitative biota characteristics
   - Plankton (phytoplankton, zooplankton, and also bacterial plankton): specific variety, number, spatial-temporal variability, and biomass.
   - Benthos (zoobenthos, phytobenthos): specific variety, number, spatial-temporal variability, and biomass.
   - Ichthyofauna: species composition, distribution, spawning migrations.
   - Sea mammals: species composition.
   - Birds: species composition, distribution.
2. Assessment and forecasting of growth conditions for rare and vanishing species
3. Assessment and forecasting of changes in ecosystems and the changes caused by the human factor

4. Assessment and forecasting of changes in commercial species of vertebrates and fishes
5. Assessment and forecasting of changes in chemical composition of tissues of marine organisms (samples of sea organisms tissues at depths of 2, 5, 10 and 20 m).

Diagnostics block of the monitoring system should include revealing, identification, and definition of biota pollutants concentrations. Forecasting will make it possible to find out pollutants accumulation rates, pollutants migration routes in food chains, and finally, to define the future condition of biological objects and their environments (Trubitsina and Sidorova 2013).

4 Conclusions

Arctic ecosystems host unique assemblages of organisms. The size and nature of arctic ecosystems make them critically important to the biological, chemical, and physical balance of the globe. Dramatic changes are threatening arctic biodiversity, the resilience of arctic species, the potential for human use of the Arctic's components, and the overall balance of its ecosystems (Arctic Marine Biodiversity Monitoring Plan … 2011).

The greater year-to-year variability in arctic biological resources (i.e. species population) compared with non-arctic regions, and the high degree of uncertainty in measurements of environmental components and in predicting impacts in the Arctic, requires that a longer period of time to establish baseline conditions for monitoring be considered (Arctic Environment Protection Strategy 1997). In this regard, it is important to accumulate scientific data from different countries and take into account the aforementioned in the article aspects of the development and implementation of biota monitoring in the Arctic.

References

AMAP (Arctic Monitoring and Assessment Programme). (1998). *AMAP assessment report: Arctic pollution issues*. Oslo: AMAP. 859 pp.

Arctic Environment Protection Strategy 1997: Guidelines for Environmental Impact Assessment (EIA) in the Arctic. Sustainable Development and Utilization. (1997). Finnish Ministry of the Environment, Finland, 50pp.

Arctic Marine Biodiversity Monitoring Plan. Marine Expert Monitoring Group. Circumpolar Biodiversity Monitoring Program. (2011). CAFF Monitoring Series Report nr. 3 Apr 2011, Iceland. 138pp.

Bashkin, V. N., Trubitsina, O. P., & Priputina, I. V. (2015). Evaluation of geo-environmental risks in zones of influence of oil and gas industry in the Russian Arctic. *North and Arctic, 19*, 92–98.

Baker, J. M., Clark, R. B., Kingston, P. F., & Jenkins, R. H. (1990). *Natural recovery of cold water marine environments after an oil spill*. Presented on the 13th Annual Arctic and Marine Oil Spill Program Technical Seminar, 111.

Burdin, K. S. (1985). *Foundations of biological monitoring*. Moscow: MGU Press. 158pp.

Diagnostic Analysis of the Environmental Status of the Russian Arctic (Advanced Summary). (2011). B. A. Morgunov (Ed.). Moscow: Scientific World, p. 172.

Federal Law "On Environmental Protection" dated January 10, 2002 № 7-FL (original version, without changes and amendments). Meeting of the legislation of the Russian Federation, Russian Newspaper. No. 6. 12.01.2002.

Matishov, G. G., Golubeva, N. I., & Burtseva, L. V. (2004). Assessment of heavy metals flows from the atmosphere with precipitations to the water area of the Barents Sea. *Evolution of marine and ground ecosystems in periglacial zones.* Theses of reports for international conference, 6–8 Sept 2004, Rostov-on-Don, 76–80.

Matishov, G. G., Nikitin, B. A., & Sochnee, O. Y. (2001). *Ecological safety and monitoring at development of hydrocarbons fields on the Arctic shelf* (p. 322). Moscow: Gazoil Press.

Matishov, G. G., Pavlova, L. G., Il'in, G. V., Checaturina, T. L., Mironov, O. G., & Petrov, V. S. (1997). *Chemical processes in ecosystems of northern seas (hydrochemistry, geochemistry, oil contamination).* Apatity: Russian Academy of Sciences, Cola Scientific Centre, Murmansk Marine Biological Institute. 404pp.

NAS (National Academy of Sciences). (2003). *Oil in the sea III: Inputs, fates, and effects*. Washington, DC: National Research Council, The National Academies Press. 265pp.

OSPAR (OSPAR Commission for the Protection of the Marine Environment of the North-East Atlantic). (2000). *Quality status report 2000, region I. Arctic waters*. London: OSPAR Commission. 102pp.

Patin, S. A. (2001). *Oil and ecology of continental shelf*. Moscow: Publishing house VNIRO. 340 pp.

Patin, S. A. (2009a). *Oil and continental shelf ecology*. Moscow: VNIRO Publishing House. 340pp.

Patin, S. A. (2009b). *Oil spills and their impact on the marine environment and biological resources*. Moscow: VNIRO. 507pp.

Scientific-Methodical Approaches to the Assessment of the Impact of Gas-Oil-Extraction on Ecosystems of Arctic Seas (on the Example of The Shtokman Project). (1997). G. G. Matishov, & B. A. Nikitin (Eds.). Apatity, 391pp.

Strategic Action Program for Protection of the Russian Arctic Environment Approved by Maritime Board at the Government of the Russian Federation. In: Minutes of Meeting dated 19 June 2009, No. 2 (11), Section I, par. 2, 26pp.

Trubitsina, O. P. & Sidorova, O. V. (2013). Monitoring of biota at the oil and gas development in the shelf zone. In: *Environmental Safety in Gas Industry: The Proceedings of III International Conference ESGI—2013.* Moscow: Gazprom VNIIGAZ, 25.

Trubitsina, O. P. (2015). Ecological monitoring of acid deposition in the Arctic region. *The Open Ecology Journal, 8*, 21–31.

Climate Cycling and Modeling in Polar Areas

Vladimir N. Bashkin and Rauf V. Galiulin

Abstract The paper shows that climate change (temperature fluctuations) on the Earth, caused by solar variations, is a cyclic natural process, which geochronologically accompanies periods of warming and cooling. At present another temperature decline is forecast. This is very important for gas production in the permafrost area of polar ecosystems since allows to support the firmness of grounds and sustainability of different construction basements, pipelines, roads and wells. The given cooling trend is bound to increase energy demand globally, as well as locally. It is suggestive that the International Energy Agency outlook projects increasing energy demand, with energy produced by oil, coal and especially natural gas, which will allow the latter to take the second place after oil in 2035. The conclusion is that such a climate dynamics is also important for the sustainable gas supply.

Keywords Climate cycling • Temperature trends • Polar region • Permafrost • Polar activity • Fuels consumption

1 Introduction

Today climate change (temperature fluctuations), and in particular the warming climate, and the impact of fuel energy, which predominantly uses the domineering, traditional energy sources—oil, coal and natural gas, is subject to ever more debate. It is believed that global warming, which the world has been witnessing over the past 50 years is mainly human-inflicted and primarily caused by carbon dioxide

V.N. Bashkin (✉)
Institute of Physicochemical and Biological Problems of Soil Sciences of Russian Academy of Sciences, Pushchino, Moscow Region 142290, Russian Federation

Institute of Natural Gases and Gas Technologies—Gazprom VNIIGAZ LLC, Razvilka, Moscow Region 142719, Russian Federation
e-mail: vladimir.bashkin@rambler.ru

R.V. Galiulin
Institute of Basic Biological Problems of Russian Academy of Sciences, Pushchino, Moscow Region 142290, Russian Federation

V.N. Bashkin (ed.), *Biogeochemical Technologies for Managing Pollution in Polar Ecosystems*, Environmental Pollution 26, DOI 10.1007/978-3-319-41805-6_8

emissions, leading to the "greenhouse effect". At the same time, about three-quarters of the human-induced carbon dioxide emissions over the past 20 years have been the result of oil, coal and natural gas extraction and burning. This statement was the cornerstone of the famous Kyoto Protocol (in effect since 1997), imposing restrictions on the human-inflicted greenhouse gases emissions, especially carbon dioxide, and providing for emissions trading. The opposite view declaring that climate change is a natural process, is also well supported especially by many natural researchers. To clarify the situation, it was important to analyze the available data about climate change, characterized by increasing as well as declining temperatures, and to study possible oil, coal and natural gas demand changes in lower temperatures to guarantee a comfortable life and dynamic development of society, particularly in the northern hemisphere. Moreover, it is known that at present most of the gas in Russia is produced in the Polar region with harsh natural conditions and a very vulnerable environment. In addition, the development of the gas industry in the future will occur in these areas. As noted above (see Bashkin 2016), the occurrence of biogeochemical cycles is largely determined by climatic parameters, which leads to a significant transformation of biogeochemical processes. This requires to review the progress of climate change both globally and regionally with special attention to Polar region.

2 Climate Change Modeling

Climate change represents fluctuations in the Earth's climate as a whole or its individual regions, which are expressed in the statistically significant variations in the weather from their multi-year values for the period from decades to millions of years. It is believed that this natural phenomenon is the result of factors that occur in the oceans such as the South (El Niño), the North Atlantic and Arctic oscillations, i.e., oscillations of the temperature of the surface water layer, as well as a reaction to the impact of other factors such as changes in the solar constant and the Earth's orbit, greenhouse effect, tectonic movement of lithospheric plates, etc.

Thus, over decades, South oscillations in the equatorial part of the Pacific Ocean as well as North-Atlantic and Arctic oscillations have contributed to climate change, which has occurred partly due to the solar energy accumulation of the global ocean and a further spread of the energy worldwide. Over a longer time thermohaline circulation, aka cycle, has occurred in the ocean caused by the density fluctuation, which the temperature and salinity fluctuation in the water has resulted in. The latter also plays a vital role in the heat redistribution.

The change of the solar constant—the amount of incoming solar electro-magnetic radiation per unit area (kW/m^2 or cal/cm^2 min)—is believed to be an important factor triggering the start of a better-known Little Ice Age (fourteenth–nineteenth centuries), with the coldest period in the seventeenth–eighteenth century. The solar constant is influenced by the Earth-Sun distance, which changes over months due to the Earth's elliptical orbit and solar variation, as phenomena and processes linked to the change in the solar magnetic activity. The changes in the Earth orbit—the result of the Earth-Moon-planets interaction—impact on the climate like the fluctuations of the Earth constant, as minor changes in the orbit bring about the redistribution of the solar irradiation on the surface.

As far as the greenhouse effect is concerned, it is the process by which thermal radiation from a planetary surface is trapped by atmospheric greenhouse gases (water vapor—36–72 %, carbon dioxide—9–26 %, methane 4–9 % and ozone—3–7 %), and is re-radiated in all directions thus resulting in an elevation of the average surface temperature above what it would be in the absence of the gases. Man's impact on the greenhouse gases balance, majorly through carbon dioxide emissions, is linked to oil, coal and gas extraction and burning. However the absence of any evidence that greenhouse gases concentration has directly affected the climate in the past tens of millions of years, points its miniscule role in climate change.

Meanwhile it is believed that the large-scale tectonic motions of the Earth's lithosphere aggravated the situation thus impacting the recent Ice Age, which ended 10,000 years ago. So, the collision of the North and the South American plates about three million years earlier resulted in the formation of the Isthmus of Panama, which shut down the flow of water between the two oceans, with the Atlantic no longer mingling with the Pacific. It was directly influenced to atmospheric heat circulation patterns, which affects climate change.

Thus, the Earth's climate is determined by the combination of many factors: over a shorter period of time (decades and centuries) separate phenomena impact on it, over a longer period of time (millennia) all the natural phenomena considered together exert influence upon the climate. Due to the above mentioned assumptions the question about the nature of the climate change on the geochronological scale arises naturally, which makes objective assessment of the phenomenon possible.

To answer these questions it is necessary to refer to the geologic time scale, as a kind of calendar of the times in the hundreds of thousands and millions of years characterizing climate change.

3 The Nature of Climate Change

It was found that climate change, particularly in the epoch of the Quaternary period—the Holocene, which has been ongoing for the last 11,000 years until the present, is characterized by a combination of periods of cooling and warming in different time intervals, indicating the cyclic nature of the change of this phenomenon on the Earth (Fig. 1) (Dansgaard et al. 1969). For instance, we should mention the reconstruction of hydrological regime of the Caspian sea, which showed that for the last 9000 to 10,000 years there were several highly expressed transgressions and the same number of regressions, i.e. respectively the rise and fall of sea level relative to land, evidence of the alternation of cool-wet and warm-dry climatic epochs at intervals of 1500–2000 years (Varushchenko et al. 1987).

Reconstruction of the climate of the Earth held a variety of geochemical, geophysical and other methods, including isotopic and paleomagnetic analysis, not only for the last 11,000 years, but before—for the last 420,000, 5 million and 65 million years, is also convinced about the cyclical nature of climate change in the distant past (Petit et al. 1999; Zachos et al. 2001; Augustin et al. 2004; Lisiecki and Raymo 2005). Meanwhile paleontology as a science about the remains of the fossil remains of plants and animals came to the conclusion that over the last 2.5 million years the share of the warm periods accounted for more than 80 % of the time (Sergeev 2010).

As can be seen from Fig. 1, closer to the present time marked the period of recent warming, when the average temperature on Earth has risen by 0.7 °C since the industrial revolution, that is, from the second half of the eighteenth century. It is assumed that a large share in the global warming observed over the last 50 years, linked to human activities, primarily emissions of carbon dioxide causing the greenhouse effect. Of these, about three quarters of all anthropogenic carbon emissions over the past 20 years resulted from the extraction and burning of oil, coal and natural gas. The existence of a temporary global warming is evidenced by the data on temperature anomalies on land and in the ocean, as deviations from long-run average, in this case, 1901–2000 (Fig. 2).

It should be noted that here the temperature anomalies more accurately describe the variability of climate over large areas, than the absolute temperature, and represent a reference system allowing to carry out fair comparisons between different territories and to carry out more accurate calculations of observed temperature trends.

To mark global warming naturally raises the question: "Modern climate change is caused by natural factors or human activities?"

So, the theory of "cyclical climate change" and "little ice age" are among the most powerful argument in the hands of the opponents of the concepts of current anthropogenic global warming (Krivenko 2010; Abdusamatov 2009; http://www.izvestia.ru/news/499668; Bashkin 2011; Bashkin and Galiulin 2012a, b, 2013). From their point of view, the modern warming is natural emergence from the "little ice age" followed by entry into a new period of cooling.

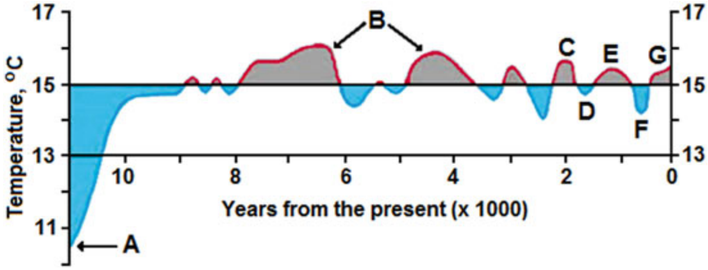


Fig. 1 Periods of warming and cooling in the northern hemisphere in the Holocene: *A*—End of the last Glacial; *B*—Climate Optimum; *C*—Roman Climate-Optimum; *D*—Episode of human migration; *E*—Medieval Warm Period; *F*—Little Ice Age; *G*—Modern Warm Period

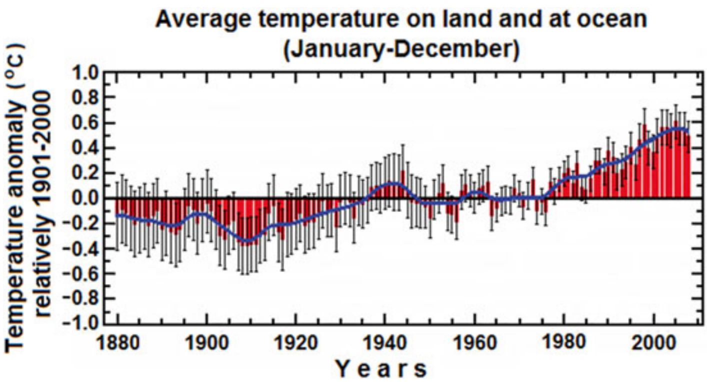


Fig. 2 Temperature anomalies on land and in the ocean during the period 1880–2010 (http://www.ncdc.noaa.gov/cmb-faq/anomalies.php)

Meanwhile, the problem of global warming is exaggerated in some developed countries from the standpoint of marketing: "the time has come for warming, the need for traditional fuels—oil, coal and especially natural gas, in particular supplied by Russia to the world market, should decrease, and, therefore, the proposed price of this energy resource should be lower than now." The current situation can be characterized by the name of recently published articles (Sergeev 2010): "Global warming, or high degree of policy?" However, in the scenario of the International energy Agency, as will be discussed below, points to a return, that is, the need for traditional fuels, especially natural gas, in the future will only grow (World Energy Outlook 2011).

In addition paleoclimatic studies associated with the study of the climate of past geological epochs, allow to doubt the validity of claims known to the Kyoto Protocol (1997) limiting emissions of greenhouse gases, especially carbon dioxide due to human activities, and allowing the trading of credits for their emissions (Samsonov 2007; Sergeev 2010). The fact is that increased levels of carbon dioxide in the atmosphere is often not preceded, but followed the warming, because when the temperature come up (for ins., due to Solar activity) carbon dioxide dissolved in the oceans (where it is 60 times greater than in air), as well as in solid rocks goes out into the atmosphere (Bashkin 2004; Bashkin and Kasimov 2004).

Thus, even for the period of the Holocene is self-evident centennial climate variability as a rhythmic process, ongoing. Noted in media now the climate is warming—this is another natural process, and the greenhouse effect is not the main cause of this phenomenon. The effect of greenhouse gases is too high, since the mass of the Earth's atmosphere in 18,375,000 billion tons, and emissions of about nine billion tons of greenhouse-gas concentration is only 0,00005 %. At such concentrations is unlikely any global changes, including climate warming.

Meanwhile, it is predicted that the emerging process of global cooling that is indirectly confirmed in Fig. 2 by the nature of the curve of temperature anomalies facing the "plateau" after 2000. The illustration of the approximation of the period of cooling is data from Fig. 3, where in the considered time interval for a duration of 137 years, characterized by cycles of warm and cold periods since the beginning of 2000-ies already is a drop in temperature, as a harbinger of another "little ice age" (Archibald 2007).

According to Abdusamatov (2009; http://www.izvestia.ru/news/499668), the Earth was on the verge of repeating the "little ice age" that gripped the northern hemisphere in XVII–XVIII centuries. Cooling occurs due to a sharp decrease of the radiation power of the Sun as the only energy source for the Earth, and, therefore, the main factor of climate change. This is due to the fact that during the 200-year cycle the solar constant varies by about 0,2 ± 0,05 %, which is noticeably reflected in the oceans, and consequently affects the climate. It is proved the relationship of solar activity cycles with large-scale climate changes on the planet and established facts that, when there is a deep minimum of solar activity, there is a cold snap. Now the Earth is entering a "little ice age", which is recently started and will reach its peak minimum temperatures by mid-century. While initially lowering the temperature is expected to be very slow, and decades later will be more active. It is expected that the temperature of the ocean will decrease by one degree, which is quite enough in Greenland grew new glaciers. Less global cooling will affect the residents to the equator and the South.

No doubt the looming cold snap will affect the increase of energy consumption, both on a global and regional scale. In this connection the question naturally arises: "What are the prospects of world energy development, especially in traditional fuels—oil, coal and natural gas, prevailing in the overall energy balance?" Moreover climate changing is closely connected with geoecological conditions of HC production in the Polar region.

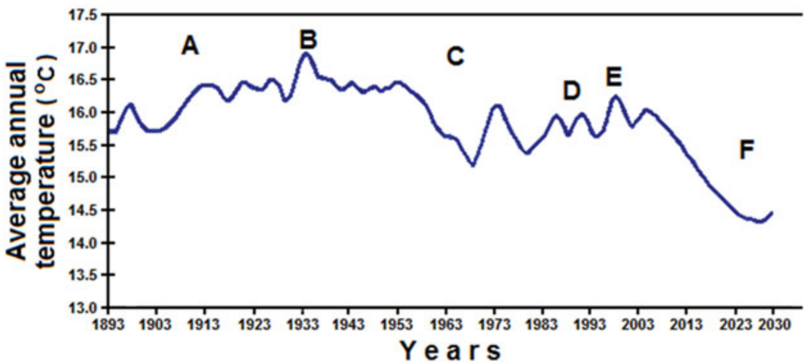


Fig. 3 The smoothed average annual temperature: *A*—the end of the latest "Little Ice Age", *B*—a warm period, *C*—a sudden drop in temperatures in 1970s, *D*—sputnik-recorded temperatures, *E*—the temperature peak of South oscillation (El Niño) in 1998, *F*—the predicted start of the minimal temperatures period (Archibald 2007)

4 Forecast of Climate Change on the Yamal Peninsula

In the long term, a particular problem can cause the transformation of the frozen strata of the Yamal Peninsula under the influence of global climate change.

Figure 4 presents modern map of average annual values of soil temperatures on the Yamal Peninsula, while Table 1 provides a predictive characteristics of the upper horizon of permafrost on this Peninsula at the different trends of changing air temperature.

The most significant changes of the depths of seasonal thawing of the soil, and consequently heat-induced throwing could occur in areas with low vegetation ground cover and in its absence (the exposed surface) under a positive temperature trend. Although this scenario does not come true, even if it could not change the conditions of existence of the permafrost zone. In the conditions of negative temperature we can see the trend of permafrost zone conservation, and even its grown.

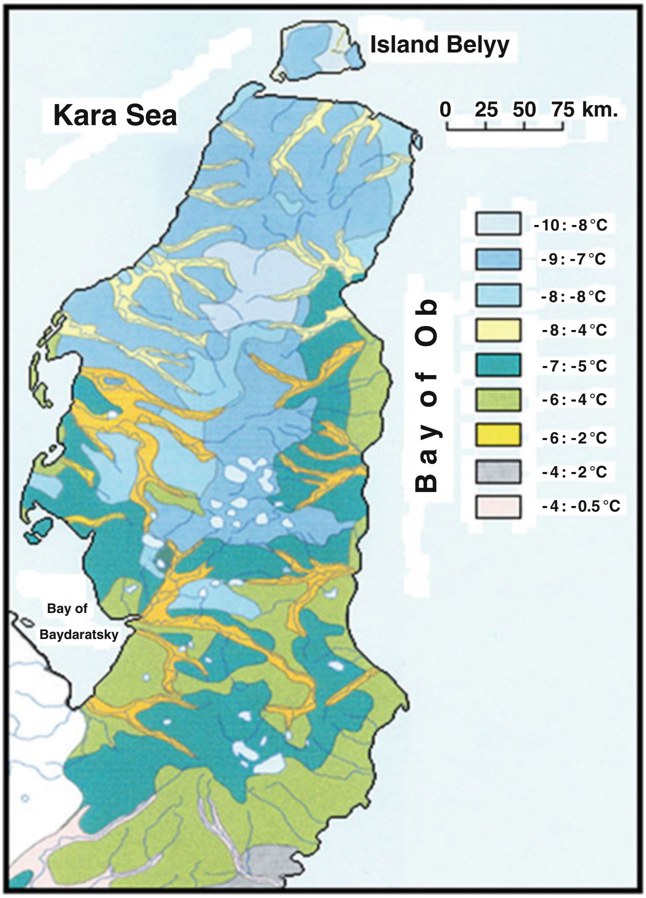


Fig. 4 Modern map of average annual values of soil temperature on the Yamal Peninsula

Table 1 Predicted characteristics of the upper horizon of permafrost on the Yamal Peninsula at the different trends of changing air temperature

Permafrost composition	Mean annual ground temperature, °C	Prognoses ground temperature, °C at trends[a]		Time of ground throwing starting at trends		Throwing depth (m) at trends	
		0,06 °C in year	–0,03 °C in year	0,06 °C in year	–0,03 °C in year	0,06 °C in year	–0,03 °C in year
Sands							
Sandy loam, loam	–7,0… −9,0 (modern time)	–2,0… −4,0	–5,0… −7,0	No throwing		Seasonal, less than 1,5	Seasonal, less than 1,0
Peats							
Sands						Up to 2,5	
Sandy loam, loam	−9,0… − 11,0	−4,0… −2,0	−6,0… −8,0	2080–2090	No throwing	Up to 2,0	Seasonal, less than 0,8
Peats						Up to 1,5	

[a]0,06 °C in year—before 2000 г.; –0,03 °C in year—after 2014 г

However, with the development of industrial infrastructure without appropriate measures of geo-environmental protection in industrial zones can cause the degradation of the permafrost zone, resulting in the degradation and transformation of permafrost, the formation of thermokarst, heaving and cracking of soils.

The risks and scale of cryogenic processes associated with possible degradation of massive ice, widespread in Central Yamal Peninsula, as a result of anthropogenic pressures will increase significantly (Fig. 5).

Subsidence of the Earth's surface as a result of the gas production on the Yamal fields can cause substantial changes in the hydrography within the territory of the deposits. However, engineering solutions, including those conducted pursuant to long-term monitoring data, are able to provide localization of the negative environmental consequences of this phenomenon.

Planned activities to reduce negative impacts on the natural environment and the protection of the territories and facilities from dangerous cryogenic processes include:

- Development of technological and special events that reduce the negative impact on near-ground atmospheric layer;
- Use of closed water systems, ensuring the prevention of surface water pollution;
- Use of specific technologies, which reduce thermal and mechanical impact on permafrost soils:
- Development of a special delicate area processing technologies;
- Protection of the sites of traditional economic management, archaeological and cultural monuments of the indigenous population.

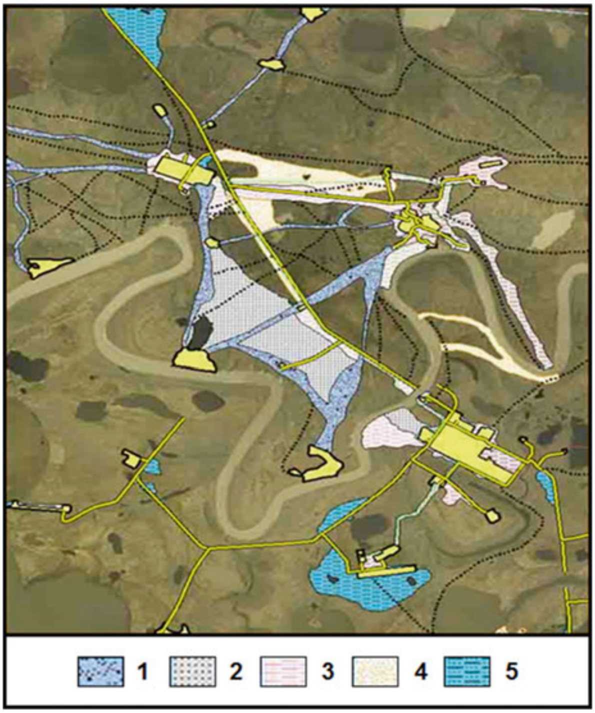


Fig. 5 Geodymanic process at gas field area on Yamal Peninsula: *1*—thermocarst, *2*—thermo-erosion, *3*—solifluction, *4*—deflation, *5*—waterlogging

5 Prospects of Development of World Energy

It is worthy pointing that according to the International Energy Agency outlook oil, coal and natural gas will remain the main energy sources up to 2035 (Fig. 6). Oil continues to be the main fuel, with consumption increasing from 4060 million tons of oil equivalent (OE) in 2008 to 4550 million toe in 2035. Coal consumption will grow from 3315 million toe in 2008 to 3670 million in 2035 peaking in around 2018 and then dropping to 250 million toe. Natural gas consumption will rise from 2600 million toe in 2008 to 4250 million toe in 2035, which will make it a second most important fuel. Nuclear power and alternative energy sources (biomass, wind, solar radiation, water and hydrogen for energy production), and large hydroelectric power stations will account for 3–12 % in the energy mix in 2035. It is a quite small share compared to the share of energy produced with oil (27 %), natural gas (25 %) and coal (22 %). Meanwhile, a more rapid growth in natural gas consumption in the future is linked to the obvious advantages of this fuel over oil and coal, for example, the cost of labor in this case is 37 times lower than in case of the extraction of the same amount of coal (in terms of oil equivalent). Moreover, gas has a high calorific value, pipelines can be installed anywhere, there is no ash after the combustion of

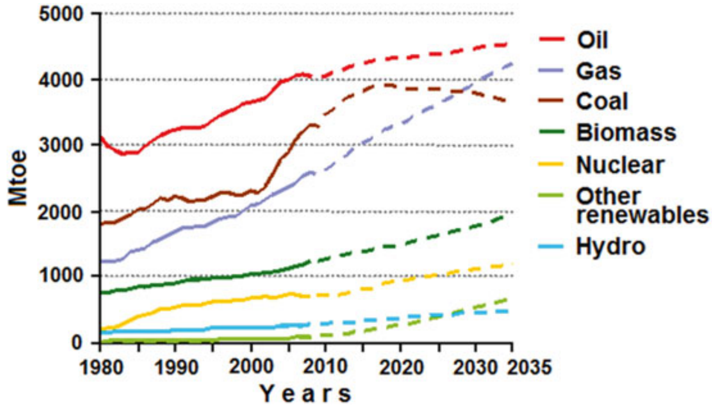


Fig. 6 The global consumption of various fuels in the gas scenario, the International Energy Agency: the *solid line* is the actual data; *dotted line*—predicted data (World Energy Outlook 2011)

natural gas, etc. The main advantage of natural gas as an energy source is the fact that over 90 % of its production is consumed as fuel at thermal power plants, factories and in households.

As mentioned above, the main gas-producing regions in the northern hemisphere are shifted into Arctic zone (Russia, Canada, USA). The earlier forecast "global warming" (it should be noted, is largely speculative) could lead to degradation of the permafrost zone and a sharp aggravation of conditions of gas production. Since this trend is not confirmed and more are expected to decrease temperature in the medium term, we noted above the forecast of increasing natural gas consumption will be accompanied by an increase of its production with reasonable technological and financial risks.

6 Conclusions

Therefore, the analysis given above points to a conclusion that climate change as a result of solar variation, is a cyclical natural processes that manifests itself on a geochronological scale in the form of alternating periods of warming and cooling. It is noteworthy that the start of the "Little Ice Age" which manifests itself in a dramatic decline in solar irradiation intensity coincided with the expected increase in oil, coal and natural gas consumption. Natural gas demand will grow exponentially due to the advantages of this resource over oil and coal. This factor will be vital for a comfortable life and dynamic development of society, particularly in the northern hemisphere during the expected "Little Ice Age".

References

Abdusamatov, K. (2009). The Sun determines the climate. *The Science and Life, 1*, 34–42.

Archibald, D. (2007). Climate outlook to 2030. *Energy and Environment, 18*(5), 615–619.

Augustin, L., Barbante, C., Barnes, P. R. F. (2004). Eight glacial cycles from an Antarctic ice core. *Nature, 429*(6992), 623–628.

Bashkin, V. N. (2004). *Biogeochemistry*. Moscow: Scientific World Publishing House. 567pp.

Bashkin, V. N. (2011). The cyclical nature of global climate fluctuations of greenhouse gases, and forecast consumption of natural gas. In: *Environmental Safety in Gas Industry. The Abstracts of II International Conference ESGI-2011* (7–8 December 2011). Moscow: Gazprom VNIIGAZ, 26.

Bashkin, V. N. (2016). Natural biogeochemical cycling in polar ecosystems. In V. N. Bashkin (Ed.), *Biogeochemical technologies for managing pollution in polar ecosystems*. NY: Springer.

Bashkin, V. N., & Galiulin, R. V. (2012a). "Golden age" of natural gas in the "little ice age". *Neftegaz.RU, 8*, 38–43.

Bashkin, V. N., & Galiulin, R. V. (2012b). Solar variation and climate change: Future temperature decline and energy demand growth. *Oil and Gas Eurasia, 9*, 48–52.

Bashkin, V. N., & Galiulin, R. V. (2013). Climate change and forecast consumption of natural gas. *Gas Industry, 1*, 58–60.

Bashkin, V. N., & Kasimov, N. S. (2004). *Biogeochemistry*. Moscow: Scientific World Publishing House. 634pp.

Dansgaard, W., Johnsen, S. J., Moller, J., et al. (1969). One thousand centuries of climatic record from camp century on the Greenland ice sheet. *Science, 166*(3903), 377–380.

Krivenko, V. G. (2010). Natural ciclica of our planet. *Bulletin of the Russian Academy of Natural Sciences, 3*, 25–29.

Lisiecki, L. E., & Raymo, M. E. (2005). A pliocene-pleistocene stack of 57 globally distributed benthic $d^{18}O$ records. *Paleoceanography*, *20*, 17pp.

Petit, J. R., Jouzel, J., Raynaud, D., et al. (1999). Climate and atmosphere history of the past 420,000 years from the Vostok ice core, Antarctica. *Nature, 399*(6735), 429–436.

Samsonov, R. O. (2007). *The program of complex development of the Yamal Peninsula and adjacent water areas*. Presentation of General Director LLC "VNIIGAZ" R.O. Samsonov on the Bureau NTS 19.12.2007.

Sergeev, A. (2010). Global warming, or high degree of policy. *Around the World, 7*(2790), 56–70.

Varushchenko, S. I., Varushchenko, A. N., & Klige, R. K. (1987). *Change of status of the Caspian Sea and drainless water bodies in Paleovalley*. Moscow: Nauka Publishing House. 240pp.

World Energy Outlook. (2011). *Are we entering a golden age of gas?* Special Report. International Energy Agency, 131pp.

Zachos, J., Pagani, M., Sloan, L., et al. (2001). Trends, rhythms, and aberrations in global climate 65 Ma to present. *Science, 292*(5517), 686–693.

Part II
Geo-environmental Risk Assessment

Evaluation of Geo-Environmental Risks in the Impacted Zones of Oil and Gas Industry in the Russian Arctic

Vladimir N. Bashkin, Olga P. Trubitsina, and Irina V. Priputina

Abstract The article deals with evaluation of geo-environmental risks (GER) in the impacted zones of oil and gas industry in the Russian Arctic. Much attention is given to GER analysis concept using acidifying pollutant critical load (CL) methodology. It is described GER review concept algorithm for acid-forming deposition in areas affected by oil and gas industry sites in the Russian Arctic. It's especially advisable for the preparation of environmental study for oil and gas projects in areas with low information availability and high degree of uncertainty.

Keywords Arctic • Acid deposition • Critical load • Geo-ecological risks • Oil and gas industry

1 Introduction

It is known that "oil and gas related activities take place throughout the Arctic on land and at sea and acidifying pollutants are emitted at every stage – from exploration to the final closure of the field…The Arctic has huge oil and gas reserves and is thought to contain around a quarter of the world's undiscovered petroleum resources: most of these in Alaska, northern Canada, Norway, and Russia, including

V.N. Bashkin (✉)
Institute of Physicochemical and Biological Problems of Soil Sciences of Russian Academy of Sciences, Pushchino, Moscow Region 142290, Russian Federation

Institute of Natural Gases and Gas Technologies—Gazprom VNIIGAZ LLC, Razvilka, Moscow Region 142719, Russian Federation
e-mail: Bashkin@issp.serpukhov.su

O.P. Trubitsina
Northern (Arctic) Federal University Named After M.V. Lomonosov, North Dvina Bank, 17, Arkhangelsk 163002, Russian Federation

I.V. Priputina
Institute of Physicochemical and Biological Problems of Soil Sciences of Russian Academy of Sciences, Pushchino, Moscow Region 142290, Russian Federation

V.N. Bashkin (ed.), *Biogeochemical Technologies for Managing Pollution in Polar Ecosystems*, Environmental Pollution 26, DOI 10.1007/978-3-319-41805-6_9

substantial amounts in offshore areas. A continuing reduction in sea ice is likely to result in an increase in oil and gas activity offshore, particularly in terms of increased marine transport of oil (as the navigation season lengthens and new sea routes open)" (Arctic Pollution 2006).

Monitoring of acid deposition in the Russian Arctic is important both in respect of transboundary pollution (circumpolar transfer of pollutants from the west) and as it relates to the development of offshore hydrocarbon production programs both anticipated and already in operation, such as the Prirazlomnaya platform operated by Gazprom Neft, a Gazprom affiliated company. Gas production is expected to be started in the near term in the Kara Sea and Ob-Taz Bay as well as in the Pechora Sea. In the longer term, the oil and gas companies (Gazprom, Rosneft) will also be looking at the Barents Sea. The monitoring of acid deposition as a result of hydrocarbon production and transportation activities in the Arctic regions must include a quantitative assessment of acidification and eutrophication risks for land-based and marine ecosystems based on international approaches to calculating the critical loads (CLs) using the established international procedures (Bashkin and Priputina 2010; Posch et al. 2007; UBA 2004), and results of previous research, some of which are cited in the referenced sources (Bashkin 2006, 2014; Bashkin and Priputina 2010, 2015; Bashkin et al. 2012, 2015; Priputina and Bashkin 2012; Trubitsina and Schwartzman 2007; Trubitsina 2002, 2013, 2015; Markelov et al. 2013; Demidova 2007; Louvar et al. 1998; Eduljee 1999; Taneja and Satsangi 2003; Porter et al. 2005).

2 GER Analysis Concept Using Acidifying Pollutant CL Methodology

In this concept, GER is determined as a two-dimensional indicator, which characterizes the probability of negative changes developing in the condition of ecosystems as the recipients of impact, and the extent of such changes (Bashkin and Priputina 2010). The quantitative assessment of GER is based on the calculation and dimensional analysis of exceeded CLs for pollutant X ($Ex(X)$) within an area affected by an industrial site. Exceeded CLs reflect the relation between exposure (actual or forecast pollutant load) and safe impact level (pollutant CL value). It is proposed that the impact on ecosystems should be calculated as the percentage of portions where CLs are exceeded in relation to the total area of a given group of portions (Bashkin and Priputina 2015).

According to Nilsson and Grennfelt, a critical load is "the quantitative estimate of an exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge" (Nilsson and Grennfelt 1988). It is important to note that the CL values are used as reference to establish the level of technological impact on ecosystems as a whole, rather than their individual components. The calculation procedures involve selecting a limited number of biogeochemical parameters the threshold levels of which will guarantee a safe technological burden on the recipients (Bashkin and Priputina 2015).

The selection of acceptability criteria for expected changes depends on the nature of ecosystems involved. The CL values are calculated for internally homogeneous receptor areas (portions) of ecosystems. For example, for ecosystems considered particularly valuable or vulnerable, the CL values must not be exceeded across 100 % of their area. Otherwise, it is proposed to apply the "95 % protection" principle according to which the load level of top pollutants is considered to be acceptable if $Ex(X) \leq 0$ for 95 % of the area in question (Bashkin and Priputina 2015; Bashkin et al. 2015).

Thus, CL values can be calculated for each recipient ecosystem, allowing to give maximum consideration to the internal heterogeneity of the given area in general.

The concept of CL has been widely adopted "as a tool for integrating information about the effects of air pollution on ecosystems, land management objectives, and regulation of atmospheric pollution" (Porter et al. 2005). Methods for the assessment of CLs for ecosystems have already been developed. They are used broadly as part of the Convention on Long-range Transboundary Air Pollution, which was signed by many countries of Europe, North America, and Central Asia. This shows that these methodological approaches to the assessment of transboundary air pollution are recognized internationally. Thus CLs are being used by most of the countries "as a tool to set goals for future acid deposition such that the environment is protected" (Taneja and Satsangi 2003).

It is proposed that the GERs of acid-forming deposition should be calculated using probabilistic modeling of exceeded CLs based on the Monte Carlo method described in the article (Bashkin and Priputina 2015).

As opposed to the conventional calculation of exceeded CLs, arrays of biogeochemical parameter values rather than isolated values (default or average) are used as input data for the simulations. Input data arrays can be prepared based on both field survey data and a review of similar projects.

The simulation for each individual receptor area results in the array of values for $E_x(X)$. The frequency distribution of these values allows calculating the probability P (0–100 %) that positive values of $E_x(X)$ will be reached for each of the portions within a given area. Each value of $P(E_x(X)>0)$ will correspond to a value of $M(E_x(X)>0)$ i.e. the total area of portions with exceeded CLs. The arrays of values (M; P) are used to determine the risk function ($R(X)$): $R(X) = F\{M, P\} = F\{M(E_x(X) > 0,\ P(E_x(X) > 0\}$, where M is the area of portions with exceeded CLs ($E_x(X)>0$); P is the probability that CLs will be exceeded.

The GER function is a distribution function. For a large number of receptor areas, the array of values (M; P) can be well approximated by a continuous normal distribution function. If the number of portions is not large, transition to normal distribution is not possible, and the function will be a step function.

The distribution function allows to calculate the probability P_1 that CLs will be exceeded in an area smaller than M_1 and for a given range of values M ($M_1 \leq M_i \leq M_2$): $P = P_2 - P_1$ (Bashkin and Priputina 2015; Bashkin et al. 2015).

3 GER Analysis Procedure Based on Acidifying Pollutant CL Methodology

The GER analysis includes risk assessment and management stages (Eduljee 1999). The algorithm of the analysis concept for acid-forming deposition in areas affected by oil and gas industry sites in the Russian Arctic is shown in Fig. 1.

It is proposed that the formal risk assessment procedure should be applied initially for the estimation of GER based on CLs of acid-forming pollutants.

The GER assessment model may comprise three steps. They are hazard identification, assessment (exposure assessment and impact assessment), and GER characteristic.

At the hazard identification stage to provide a "qualitative prediction of the impact" (Bashkin 2006), it is necessary to identify emission sources, determine possible scenarios of man-induced impact, list all the pollutants contained in the plant's emissions, identify acid-forming pollutants in plant's emissions, determine the list of potential impact recipients (ecosystems within the area affected by the project) and possible negative changes in their condition, and rank them.

This is followed by the assessment stage, which consists of the exposure assessment and effects. This requires a quantitative estimation of impact based on available information on hazards and recipients.

According to Bashkin and Priputina (2010) the exposure assessment is a quantitative determination of the intensity of man-induced load (exposure doses) for identified recipient groups, depending on the pollutant (or pollutant metabolite) migration routes and impacting media. This type of assessment must include a detailed characteristic of the potential recipient groups (including the division of recipient ecosystems into receptor areas), determination of the CL value for acid-forming pollutants in the given area (calculated according to the Russian Federation's commitments under the Convention on Long-range Transboundary Air Pollution), calculating the actual load level of acid-forming pollutants (g/ha per annum or eq/ha per annum), determining the acid-forming pollutant flows and propagation limits, estimating the exposure concentrations.

At the impact assessment stage ("dose-effect" relation), it is necessary to determine the threshold exposure levels, i.e. reference doses that characterize quantitative relations between actual doses of acid-forming pollutants and the corresponding adverse effects in the condition of recipients. This must include determination of the CL value for acid-forming pollutants, which will characterize the maximum acceptable load level for the identified recipients in order to parameterize reversible and irreversible impacts. It is recommended to determine the potential stability of ecosystems at this stage.

GER characteristic is the final procedure of actual risk assessment, which integrates all data obtained during the previous stages. It identifies indicators of individual risk types, allows to determine the total GER and must include calculation of changes in the condition of recipients, probability that they will occur, and determination of acceptability of such changes against the selected criteria. It is proposed

STAGES OF GER ASSESSMENT	CONTENT OF THE STAGES
I. Hazard Identification	1. Emission sources 2. Possible scenarios of man-induced impact 3. Comprehensive list of pollutants 4. List of acid-forming pollutants 5. List of potential impact recipients and its ranking 6. Sources of uncertainty and reliability assessment
II. Assessment A) Exposure Assessment	1. Detailed characteristic of the potential recipient groups 2. Determination of the CL value of acid-forming pollutants 3. Calculation of the actual load level of acid-forming pollutants 4. Determination of acid-forming pollutant flows and its boundaries 5. Assessment of the exposure concentrations 6. Sources of uncertainty and reliability assessment of calculations
B) Impact Assessment	1. Determination of the reference doses 2. Parameterization of the reversible and irreversible impacts 3. Determination of the potential stability of ecosystems 4. Sources of uncertainty and reliability assessment of calculations
III. GER Characteristic	1. Calculation of GER for different groups of effects 2. Calculation of GER for different groups of effects recipients 3. Calculation of GER for different groups of exposure scenarios 4. Uncertainty analysis of the results obtained

STAGES OF GER MANAGEMENT	CONTENT OF THE STAGES
I. Identification of Hazard Degree	Comparative characteristic of GER for different groups of effects, recipients and exposure scenarios
II. Risk Acceptability	1. The comparison process is based on the "cost - profit" method. 1.1. Profit from the operation of the oil and gas site in the Arctic region; 1.2. Losses due to operation of the oil and gas site in the Arctic region; 1.3. The availability and ability of regulatory measures to mitigate the negative environmental impact 2. Determination of the type of decision-making: 2.1. Risk is totally acceptable; 2.2. Risk is partly acceptable; 2.3. Risk is totally unacceptable.
III. Control Proportions	Selection of one of the "typical" measures which reduces (in the first and second cases – 2.1 and 2.2) or eliminates (in the third case – 2.3) the GER
IV. Regulatory Decision Making	Determination of the legislative capacity (laws, ordinances, instructions) to implement the "typical" measure, which was determined during the previous stage.

Fig. 1 GER review concept algorithm for acid-forming deposition in areas affected by oil and gas industry sites in the Russian Arctic

that risk should be characterized in two stages. At the first stage, it is necessary to perform the deterministic calculation of exceeded CLs based on averaged input data. If receptor areas with $E_x(X) > 0$ are detected, a GER assessment using simulation methods should be carried out at the second stage (Bashkin and Priputina 2015; Bashkin et al. 2015).

The GER assessment study must be finalized by reviewing the uncertainty of obtained results. For this purpose, the sources of uncertainty must be described for each risk assessment stage and the accuracy of calculation results must be estimated. It is proposed that the results of GER assessment should be used to rank individual design alternatives and to develop approaches to mitigating the environmental impact as part of the environmental impact assessment procedure for projects (Bashkin 2014).

The GER management for acid-forming deposition in areas affected by oil and gas industry is a decision-making procedure aimed to achieve acceptable levels of total GERs associated with existing or future industrial sites. This procedure takes into account GER estimation for acid-forming deposition as well as technological and environmental capabilities of risk prevention, reduction, monitoring, response, communication, etc.

The GER control philosophy must incorporate strategic and tactical objectives. Strategic objectives should reflect the commitment to achieve the maximum possible level of public welfare in general, tactical objectives should pursue an improvement in the safety of all groups of live forms in the Arctic region.

The GER management model may comprise four steps.

The first step is related to risk characteristic. During the initial stage, a comparative characteristic of GER is given for different groups of effects, recipients and exposure scenarios to identify priorities. The degree of hazard (harm) is determined at the final stage of risk assessment.

The second step is determining the acceptability of risk. The risk is compared to a number of social and economic factors: profit from the operation of existing or future oil and gas site in the Arctic region; losses due to operation of the oil and gas site in the Arctic region; are or can regulatory measures be applied to mitigate the negative environmental impact. The comparison process is based on the "cost–profit" method.

The comparison of "non-risk" and "risk" factors is an essential part of the risk management process. Three alternative decisions are possible: (1) risk is totally acceptable; (2) risk is partly acceptable; (3) risk is totally unacceptable.

The third step is the determination of control proportions, which consists in the selection of one of the "typical" measures, which reduces (in the first and second cases) or eliminates (in the third case) the GER.

The fourth step is regulatory decision making, i.e. determining the legislative capacity (laws, ordinances, instructions) to implement the "typical" measure, which was determined during the previous stage. This step is the final step of the GER management process, which integrates all the previous steps and the GER assessment stages into the overall decision-making process and the overall GER analysis concept for acid-forming deposition in the areas affected by oil and gas industry sites in the Russian Arctic.

4 Conclusion

The proposed GER concept, including the risk assessment procedure for ecosystems related to acid-forming emissions from oil and gas sites in the Russian Arctic, allows to perform a quantitative assessment of not only the predicted changes in the condition of ecosystems but also the probability of their occurrence. It allows to provide a detailed characteristic of ecosystems as subjects of technological impact. In addition, this procedure takes into consideration interrelations between individual components of land and water-based Arctic ecosystems and the natural variability of the parameters, which characterize the condition of these components. The quantitative GER assessment is advisable for the preparation of environmental study for oil and gas projects in areas with low information availability and high degree of uncertainty.

Currently, the GER assessment is already used in the practice of Gazprom's gas production companies (Markelov et al. 2013), and its continued use by other oil and gas companies will allow to both estimate the probability of such risks occurring during the operation of polar fields and determine the appropriate ways to manage such risks.

References

Arctic Pollution 2006: Acidification and Arctic Haze. (2006). Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway (p. 39).

Bashkin, V. N. (2014). *Biogeochemistry of polar ecosystems in gas industry impacted zones*. Moscow: Gazprom VNIIGAZ Publishing House. 302pp.

Bashkin, V. N. (2006). *Modern biogeochemistry: Environmental risk assessment* (2nd ed.). Berlin, London: Springer Publishers. 444pp.

Bashkin, V. N., & Priputina, I. V. (2010). *Management of environmental risks at emission of pollutants*. Moscow: Gazprom VNIIGAZ Publishing House. 189pp.

Bashkin, V. N., & Priputina, I. V. (2015). (Geo)ecological risk assessment in gas industry development scenarios. *The Open Ecology Journal, 8*, 65–68.

Bashkin, V. N., Arno, A. B., Arabsky, A. K., Barsukov, P. A., Priputina, I. V., & Galiulin, R. V. (2012). *Retrospective and forecast of geoecological situation on gas-condensate fields of the far north*. Moscow: Gazprom VNIIGAZ Publishing House. 280pp.

Bashkin, V. N., Trubitsina, O. P., & Priputina, I. V. (2015). Evaluation of geo-environmental risks in zones of influence of oil and gas industry in the Russian Arctic. *North and Arctic, 19*, 92–98.

Demidova, O. A. (2007). Critical loads approach in ecosystem risks assessment. *Problems of Risk Analyses, 3*, 50–2.

Eduljee, G. (1999). Risk assessment. In J. Petts (Ed.), *Handbook on environmental impact assessment: 2 volumes* (pp. 374–404). Oxford: Blackwell Science Ltd.

Louvar, J. T., Louvar, B. D., & Hall, P. (1998). *Health and environment risk analysis. Fundamentals and applications*. NJ: Prentice Hall PTR. 678pp.

Markelov, V. A., Andreev, O. P., & Kobylkin, D. N. (Eds.). (2013). *Sustainable development of gas industry*. Moscow: Nedra. 211pp.

Nilsson, V., & Grennfelt, P. (1988). *Critical loads for sulfur and nitrogen*. Report from a workshop held at Stockloster. UN/ECE and Nordic Council of Ministers, Copenhagen.

Porter, E., Blatt, T., Potter, D., & Huber, C. (2005). Protecting resources on federal lands: Implications of critical loads for atmospheric deposition of nitrogen and sulfur. *BioScience, 7*, 603–612.

Posch, M., Hetteling J.-P., & Slootweg, J. (2007). Critical loads and dynamic modeling of nitrogen. In: *Critical loads of nitrogen and dynamic modeling*. CCE Progress Report 2007, Bilthoven, The Netherlands (pp. 41–51).

Priputina, I. V., & Bashkin, V. N. (2012). Environmental risks related to technogenic pollution: analysis of approaches and estimation methods. *Problems of Risk Analysis, 5*, 12–25.

Taneja, A., & Satsangi, G. S. (2003). Critical load—A new approach, concept and application. *Asian Journal of Experimental Sciences, 1 and 2*, 23–34.

Trubitsina, O. P. (2002). Global/regional acid deposition. In Y. Schwartzman (Ed.), *Ecology of the Northern Territories in Russia. Problems Forecast of the Situation, the Development, Solutions, Proceedings of the International Conference* (pp. 399–403). Arkhangelsk: Arkhangelsk State Technical University Press.

Trubitsina, O. P., & Schwartzman, Y. G. (2007). Geoecological condition of atmospheric air in the North of the Russian Plain. *Vestnik the Arkhangelsk State Technical University, Series Applied Ecology, 70*, 151–163.

Trubitsina, O. P. (2013). Loads of acid deposition in the north of the Russian plain. *Vestnik NArFU, Series of Natural sciences, 4*, 44–49.

Trubitsina, O. P. (2015). Ecological monitoring of acid deposition in the arctic region. *The Open Ecology Journal, 8*, 21–31.

UBA. (2004). *Manual on methodologies and criteria for modeling and mapping critical loads and levels and air pollution effects, risks and trends*. Chapter 5.5: Critical loads of cadmium, lead and mercury, Berlin (pp. 39–73). Available at: http://www.icpmapping.org.

Biogeochemical Cycling and SMB Model to Assess Critical Loads of Nitrogen and Acidity for Terrestrial Ecosystems in the Russian Arctic

Irina V. Priputina, Vladimir N. Bashkin, and Arina V. Tankanag

Abstract The article presents the results of evaluation of critical loads (CLs) of acidity and nutrient nitrogen for terrestrial ecosystems of the Yamal Peninsula, which is the region of largest gas fields in Russia. CLs calculation was carried out using SMB model widely applied for the calculation of CLs and their exceedances in the framework of the Convention on LRTAP. The calculations have been performed using three temperature scenarios: current climate, warming and cooling. The calculated values of CLs for acidifying effects of atmospheric deposition in conservative scenario were ranged from less than 100 up to 600 eq ha^{-1} yr^{-1}, mean values were equal to 200–400 eq ha^{-1} yr^{-1}. The values of CLs of nutrient nitrogen were in average 140–350 eq ha^{-1} yr^{-1} or 2–5 kg N ha^{-1} yr^{-1}. According to our estimation, the decrease an annual temperature on 2 °C may lead to reducing CLs nutrient nitrogen in the north of the peninsula, and CLs acidity in the southern part. The temperature increase on 1 °C may have a positive influence on values of CLs acidity in northern, and CLs nutrient nitrogen in central and southern part of the Yamal Peninsula.

Keywords Nitrogen deposition • Critical loads • Arctic ecosystems

I.V. Priputina (✉)
Institute of Physicochemical and Biological Problems of Soil Science of Russian Academy of Sciences, Pushchino, Moscow Region 142290, Russian Federation
e-mail: i.priputina@gmail.com

V.N. Bashkin
Institute of Physicochemical and Biological Problems of Soil Science of Russian Academy of Sciences, Pushchino, Moscow Region 142290, Russian Federation

Institute of Natural Gases and Gas Technologies—Gazprom VNIIGAZ LLC, Razvilka, Moscow Region 142719, Russian Federation

A.V. Tankanag
Institute of Cell Biophysics of Russian Academy of Sciences, Pushchino, Moscow Region 142290, Russian Federation

V.N. Bashkin (ed.), *Biogeochemical Technologies for Managing Pollution in Polar Ecosystems*, Environmental Pollution 26, DOI 10.1007/978-3-319-41805-6_10

1 Introduction

According to many available data, anthropogenic emission of sulfur (S) and nitrogen (N) is considered among the main sources of the Arctic ecosystems pollution. High levels of S emissions in 1970s and 1980s were associated with production of copper and nickel from sulfur-bearing ores on the Kola Peninsula and in Norilsk region, Russia (Hole et al. 2006). Beginning from 1990s, there are decreasing trends of acidic deposition within the Arctic. Anthropogenic N deposition in the Arctic region is linked with human activity on natural fuel extraction and its transport by pipelines. Plans for the development of hydrocarbon fields in the Northwest Russian Arctic (Saneev et al. 2015) suggest that ecosystems of this region might receive elevated inputs of reactive N in the next decades.

Ecological consequences of impacts of enriched N deposition include risks of damage of natural biogeochemical cycles resulting in eutrophication and acidification of ecosystems. Arctic and sub-arctic ecosystems are originally limited with available soil nitrogen. Being both a nutrient and acidifying agent, air N deposition stimulates a wide range of direct and indirect actions, which affect all components of natural ecosystems including vegetation, microbiota and soils (Bobbink and Hettelingh 2011). According to Pardo et al. (2015), acidic tundra may be more sensitive to N deposition than non-acidic tundra. Negative influence of increased N deposition on lichens, which are typical species of tundra vegetation, and important food resources for reindeers, may be more expressed in the presence of other species (grasses, sedges and shrubs) in the low and mid arctic than in the high arctic where lichens have less competitors.

Large gas fields in the Russian Arctic are located on the Yamal Peninsula. The company “Gazprom”, which is the main developer of these gas fields, pays an attention to issues of ensuring environmental safety in the development of the Yamal Peninsula fields, to prevent and minimize environmental damage to the natural environment and traditional lifestyle of the local peoples. There has been performed a number of studies aimed at the analysis of ecological risks to natural complexes of the Yamal Peninsula in connection with various scenarios of development of territory. In the frame of these researches, regional assessments of critical loads (CLs) of nutrient nitrogen and acidity for terrestrial ecosystems of the Yamal Peninsula were completed (Bashkin et al. 2009; Bashkin and Priputina 2010). In light of the widely discussed issues of climate change, estimates of the quantities CL carried out according to three scenarios of temperature conditions: conservative (appropriate current climate of the ratio of mean annual temperature and precipitation), cooling (reduction of the current average annual temperature in 2 °C) and warming (temperature increase of 1 °C).

2 Materials and Methods

2.1 Area Under Investigation

The Yamal Peninsula is located in the north of the Western Siberia between 68°–73°N and 66°–73°E (Fig. 1). Its area is about 122,000 km^2. Most of the natural gas reserves are concentrated in five fields with total stocks more than 500 billion m^3.

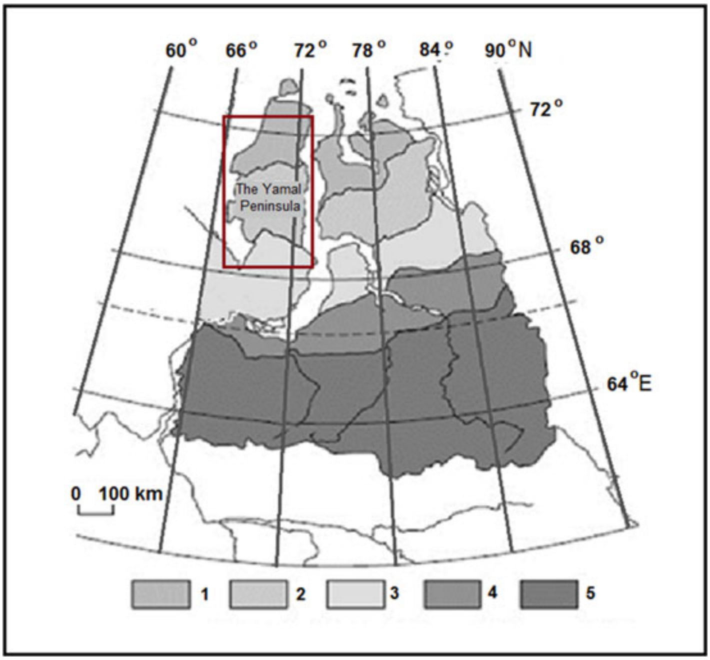


Fig. 1 Natural zones of the Yamal Peninsula (based on: Kolosova 1980) *1*—high Arctic tundra, *2*—typical (middle) tundra, *3*—south (low) tundra, *4*—sub-tundra, *5*—north taiga. Area under study is highlighted by *red color*

Natural conditions of this region are characterized by a harsh climate with long winter and permafrost. Typical tundra landscapes with numerous lakes and bogs are dominated in central and southern part of the peninsula. The ecosystems of northern part are presented by arctic tundra.

2.2 *Calculation of CL of Nutrient Nitrogen and Acidity*

Estimation of CLs of nutrient nitrogen and acidity for terrestrial ecosystems in the Yamal Peninsula has been made using Simple Mass Balance (SMB) model (UBA 1996, 2004), which applies to calculate CLs in the framework of the Convention on Long-Range Transboundary Air Pollution (http://live.unece.org/env/lrtap/). Detailed description of algorithms and important steps in deriving CLs are presented on the website of ICP modelling and mapping (http://icpmapping.org/Mapping_Manual). Equations and data sources used in our estimations of CL of nutrient nitrogen are summarized in Table 1. The similar information to calculate CL acidity is presented in Table 2.

Table 1 Algorithm and sources of the data for calculation CL of nutrient nitrogen (eutrophication)

Symbol	Specification	Unit	Equation or data source
$CL\ (N)_{nut}$	Critical loads of nutrient N	eq $ha^{-1}\ yr^{-1}$	**$= CL\ (N)_{min} + N_{le(acc)}/(1 - f_{de})$**
$CL\ (N)_{min}$	Critical load of minimal N	eq $ha^{-1}\ yr^{-1}$	**$= N_{upt} + N_{im}$**
N_{upt}	Net removal of N in harvested vegetation	eq $ha^{-1}\ yr^{-1}$	**$= Y_{hpp} * [N]_{hpp}$**
Y_{hpp}	Harvested biomass	eq $ha^{-1}\ yr^{-1}$	Literature data (Table 4)
$[N]_{hpp}$	N concentration in harvested biomass	eq kg^{-1}	Literature data (Table 3)
N_{im}	N immobilization	eq $ha^{-1}\ yr^{-1}$	
$N_{le(acc)}$	Acceptable N leaching	eq $ha^{-1}\ yr^{-1}$	**$= Q_{le} * [N]_{acc}$**
Q_{le}	The precipitation surplus (annual water flux)	$m^3\ yr^{-1}$	$= P - ET$
P	Precipitation	$m^3\ yr^{-1}$	Regional data from http://www.meteorf.ru
ET	Evapotraspiration	$m^3\ yr^{-1}$	Based on (Kolosova 1980)
$[N]_{acc}$	Acceptable N concentration in soil solution	eq m^{-3}	Recommended data (Table 5.7 in Mapping Manual, 2004)
f_{de}	Denitrification fraction	–	Recommended data (Table 5.9 in Mapping Manual, 2004)

2.3 Land Cover and Soil Data

The distribution of different type of vegetation for the Yamal Peninsula area was described using Land Use IGBP Map of EDC DAAC (1997). Spatial distribution of soil characteristics (soil type, texture classes and others) were taken from FAO UNESCO Soil Map (1995) and updated using national maps and literature data. A combined map with the information on soil and vegetation was generated by overlaying.

3 Results and Discussion

3.1 Biogeochemical Parameters that Affect the Values of CLs of Nutrient Nitrogen and Acidity

The calculation of CLs for acidifying and eutrophic compounds is based on the parameterization of the main biogeochemical fluxes of elements in ecosystems. Specificity of formation and the analysis of the intensity of these flows in different types of ecosystems of the Yamal Peninsula are discussed below.

Table 2 Algorithm and sources of the data for calculation CL of nutrient nitrogen (eutrophication)

Symbol	Specification	Unit	Equation or data sources
CL $(S)_{max}$	Critical load for S (acidifying compounds)	eq ha^{-1} yr^{-1}	= $\mathbf{BC_{dep} + BC_{we} - Cl_{dep} - Bc_{upt} - ANC_{le(crit)}}$
$\mathbf{BC_{dep}}$	Air deposition of base cations (BC = Ca + Mg + K + Na)	eq ha^{-1} yr^{-1}	Regional data from http://www.meteorf.ru
$\mathbf{Cl_{dep}}$	Air deposition of chlorine ions	eq ha^{-1} yr^{-1}	Regional data from http://www.meteorf.ru
$\mathbf{BC_{we}}$	BC weathering in soil	eq ha^{-1} yr^{-1}	$\mathbf{= z * (BC_w(T^0) * 2{,}6^{(A/T0 - A/T)})}$
$BC_w(T^0)$	Weathering of BC at temperature 281 °K	eq ha^{-1} yr^{-1}	Constant values depending on soil texture
T	Regional annual temperature	°K	Regional data from http://www.meteorf.ru
Z	Soil depth	m	Literature data (Dobrovolsky 1967, 1979)
A		–	Default value (A = 3600)
$\mathbf{Bc_{upt}}$	Net removal of Ca, Mg ad K (Bc) in harvested vegetation	eq ha^{-1} yr^{-1}	$\mathbf{= Y_{hpp} * [Bc]_{hpp}}$
$\mathbf{Y_{hpp}}$	Harvested biomass	kg ha^{-1} yr^{-1}	Literature data (Table 4)
$\mathbf{[Bc]_{hpp}}$	Bc concentration in harvested biomass	eq kg^{-1}	Literature data (Table 3)
$\mathbf{ANC_{le(crit)}}$	Acid Neutralizing Capacity	eq ha^{-1} yr^{-1}	$\mathbf{= Q * ([H]_{(crit)} + K_{gibb} * ([H]_{(crit)})^3)}$
Q	The precipitation surplus	m^3 yr^{-1}	= P – ET
P	Precipitation	m^3 yr^{-1}	Regional data from http://www.meteorf.ru
ET	Evapotraspiration	m^3 yr^{-1}	Based on (Kolosova 1980)
$\mathbf{[H]_{crit}}$	Critical concentration of hydrogen ions in soil solution	eq m^{-3}	Based on proton criterion (critical pH): $[H]_{crit}$ = 0.1 eq m^{-3}
K_{gibb}	Gibbsite equilibrium constant	eq^6 m^2	Default value (K_{gibb} = 300)

3.1.1 The Fixation of Nitrogen and Basic Cations (Ca, Mg, K) in Plants Biomass

According to (Bazilevich 1993), the annual total production of ground parts of vegetation in typical subarctic shrub-grass tundra is 680–2000 kg ha^{-1}, but a part of ligneous fraction is only 30–80 kg ha^{-1}. In the swamps superciliously typical tundra productivity is equal to about 2000 t ha^{-1} yr^{-1}, and in the swamps of the South tundra is 2–4.3 t ha^{-1} yr^{-1}. Unlike the conditions of the forest area, the annual litter in the tundra zone is significantly lower. The green leaves and herbaceous vegetation is preserved under the snow in the composition of the pool of living biomass. Feature of tundra ecosystems is the predominance of underground phytomass. The ratio of aboveground and underground parts is 1:4 on watersheds and 1:2 slopes and

Table 3 Average concentrations of nitrogen and base cations in tundra vegetation (based on: Bogatyrev 1976)

Type of vegetation	**N**		K		Ca		Mg		**Bc**
	g kg^{-1}	eq kg^{-1}	g kg^{-1}	eq kg^{-1}	g kg^{-1}	eq kg^{-1}	g kg^{-1}	eq kg^{-1}	eq kg^{-1}
Willow (*Salix glauca*), branches	2	0.14	2.5	0.06	3	0.15	1.2	0.10	0.31
Small shrubs	7	0.50	4	0.10	5	0.25	2	0.16	0.52
Sedge	8.5	0.61	14	0.36	2	0.1	1.5	0.12	0.58
Herbs	10	0.71	13	0.33	8	0.4	3	0.25	0.98
Mosses	6	0.43	3	0.08	10	0.5	4	0.33	0.91
Lichens	2.2	0.16	2.5	0.06	2	0.1	0.6	0.05	0.21

terraces. According to Bogatyrev (1976), the true aboveground biomass growth is about 50–170 kg ha^{-1} yr^{-1} in shrub-sedge-moss tundra and 250–300 kg ha^{-1} yr^{-1} in wetlands with domination of the shrub-sedge-moss vegetation.

Many plant species of tundra vegetation (dwarf shrubs, lichens, mosses, sedges, grasses and forbs) are used as forage for reindeer husbandry. Harvest edible mass ranges from 10 (in sphagnum bogs) up to 400 kg ha^{-1} (in Willow and Birch pastures) (Borinevich et al. 1963). On average, a consumption may be estimated in about 100 kg ha^{-1} (of dry weight). The concentrations of nitrogen and cations (Ca, Mg, K) in the composition of the vegetation are presented in Table 3. The most active nitrogen accumulates in the composition of herbs and sedges, and the minimum content of typical lichens and woody parts of the biomass of shrub willow. Maximum concentrations of cations are found in herbs and mosses, and the minimum in lichens.

Based on the data from Table 3, we calculated the potential parameters of the fixation of nitrogen in the production of biomass ground parts of vegetation (Table 4). The evaluation was carried out for two variants: in the first case, the calculated amount of nitrogen accumulated in annual growth, while the second took into account only the portion of biomass that is removed from the ecosystem as a result of deer grazing. The obtained values vary from 0.2 to 3.5 kg N ha^{-1} yr^{-1}. In both cases, the calculations of the maximum parameters N_{upt} obtained for willow herb, the minimum—for lichen tundra. The literature presents the English authors data (Hall et al. 2001), in which the fixation of nitrogen in the vegetation of raised bogs in the Arctic zone is estimated at 0.5 kg N ha^{-1} yr^{-1} that is below our estimate.

3.1.2 Immobilization of Nitrogen in the Soil

The deposition of nitrogen in the composition of soil organic matter in tundra ecosystems occurs slowly, due to low productivity of the plant communities. The process of humification of plant residues in a typical and shrub tundra slowed down. In the first year is lost no more than 30–40 % of the initial weight of the plant material, after 2 years of 30–70 % of the plant material is not decomposed (Parinkina 1978).

Table 4 The intensity of nitrogen fixation in the ground vegetation biomass of tundra ecosystems

Type of vegetation	Productivity, kg ha^{-1} yr^{-1}		N fixation in biomass, kg ha^{-1} yr^{-1}	Nitrogen removal with harvested biomass, kg ha^{-1} yr^{-1}
	Total[a]	Pasture[b]		
Herb willow tundra		400		3.5
Including green biomass	300		2.7	
Only wood part	80		0.2	
Willow-herb-moss tundra		200		1.7
Including green biomass	170		1.6	
Only wood part	40		0.1	
Shrub-herb-moss tundra	200	150	1.5	1.1
Willowo-sedge marshes		100		0.8
Including green biomass				
Only wood part				
Shrub-lichen tundra	200	150	0.7	0.5
Lichen tundra	170	100	0.5	0.3
Sedge marshes	250	50	2	0.4
Sphagnum bogs	250	10	1.5	

[a]Based on: Bogatyrev (1976) and Bazilevich (1993)

[b]Based on: Borinevich et al. (1963)

A major factor in the mineralization of fresh litter in the first year are abiotic factors, and first of all, moisturizing, and not the activity of the microbiota. Therefore, in dry years the intensity of decomposition of the litter, and, consequently, the release of nutrients are slower. Migration of organic matter in the profile of tundra soils is weak, 2–4 times slower than in the middle taiga podzols (Archegova and Tsypanova 1968). According to Swedish authors (Ineson et al. 1996), long-term immobilization in ecosystems of Northern Sweden ($pH_{soil}=5.5$, $N_{dep}=2$ kg N/ha per year) is 0.5 kg N ha^{-1} yr^{-1}. In the case of ecosystems of the Yamal Peninsula, this value can be considered as the upper limit of this parameter. In our calculations the value of the $N_{im}=0.3$–0.5, depending on ecosystem productivity; believed that $N_{im}<N_{upt}$.

3.1.3 Leaching of Nitrogen (N_{le_acc}) and Critical Alkalinity (ANC_{le_crit})

The annual average precipitation for most parts of the territory—260 mm (250–500 mm), in the North and Northwest of the Peninsula is less than 250 mm (National Atlas 2007). Evaporation ranges from 100–200 in the Northern part up to

200–300 mm per year in the South of the peninsula. The parameters of the total annual flow are divided into two approximately equal parts: in the North—100–200 mm per year, in South—200–400 mm per year.

The vegetation cover of the tundra zone is very diverse: from lichens and mosses to grasses, herbs and shrubs. *In vivo* tundra vegetation develops in conditions of low nitrogen content in the soil (on average 0.1–0.5 %); the share of mineral forms of nitrogen is small and they are mostly ammonium compounds. It is assumed that tundra vegetation formed under conditions of lack of nitrogen, must be sensitive to its increased concentration in the soils. When exceeding the critical concentration of nitrogen in the soil solution of 0.2–0.4 mg N l^{-1} possible effects of imbalance between lichen and dwarf shrub vegetation, at concentrations of 1–2 mg N l^{-1} possible violations in the ratio shrubs—grasses, and 3–5 mg N l^{-1}—between cereal species and grasses. The critical pH of the soil solution depending on the vegetation type is sized of 4–5.

Taking the value of Q = 200 mm yr^{-1} and the corresponding critical nitrogen concentration in the soil solution, the parameters of the acceptable leaching of nitrogen from soil and groundwater runoff constitute the ecosystems with the participation of lichens and mosses—0.4–0.8, dwarf shrub tundra—1–2, grassy and sedge communities—2–4 kg N ha^{-1} yr^{-1}.

3.1.4 Denitrification

According to various researchers (Dobrovolsky 1967, 1979; Gerasimova 1987; Vasilevskaya et al. 2006), tundra soils are characterized by low rate of mineralization of organic residues, which determines the gradual entrance of nutrients. The prevalence of weakly acidic environment leads to the development of processes of ammonification. Nitrifying bacteria prefer a slightly alkaline environment and presence in soil Ca, Mg, K, Zn, Fe, Mn, Co and other metals in the form of carbonates; acid reaction decreases dramatically an activity of nitrification (Peive 1961). Nitrifying bacteria are aerobic microorganisms and thrive in the presence of oxygen. Temperature conditions are also important for activities of nitrifying bacteria. The bulk of the roots in tundra soils is concentrated in a narrow surface layer, whereby there is practically no free oxygen. In conjunction with the waterlogging and the presence of permafrost, this circumstance leads to the predominance of the recovery mode, which is unfavorable for the development of nitrification. Researchers noted that the dominant forms of mineral nitrogen in these soils are ammonium compounds. Necessary conditions for denitrification are the presence in the soil of available nitrate, organic matter and anaerobic conditions. Tundra soils are generally waterlogged, and the content of nitrate nitrogen and well-decayed organic matter in them is small. The situation may change in the presence of an external source of nitrogen such as atmospheric deposition. In this case, their excess can be included in the processes of denitrification and leaching.

Recommendation (UBA 1996, 2004) suggests that $N_{de} = 0$ if the magnitude of nitrogen inputs from atmospheric deposition are lower than the total value of N_{upt}

and N_{im}. The flow of nitrogen deposition in the more Western parts of the tundra zone of the Russian Federation is 1.5–2 kg N ha^{-1} yr^{-1}. According to our calculations, the total pool of nitrogen required for the production of biomass and fixed in soil organic matter in many types of tundra ecosystems is less than 2 kg N ha^{-1} yr^{-1}. In other ecosystems (typically, wetlands) these parameters are comparable; the calculated values N_{de} up 0.4–0.7 kg N ha^{-1} yr^{-1}, which agrees with the results of expert assessments (UBA 1996), according to which the intensity of denitrification in the Northern ecosystems is 0.1–3 kg N ha^{-1} yr^{-1}.

3.2 Critical Loads of Nutrient Nitrogen and Acidity

The calculated values of CL for acidifying effects of atmospheric deposition range from less than 100 up to 600 eq ha^{-1} yr^{-1}; for most of the sites the level of recovery of acid anions is 200–400 eq ha^{-1} yr^{-1}. The minimum values were obtained for swamps, which have low rate of weathering of soil minerals, and limited potential of neutralization of acid deposition (Fig. 2). Results of our estimations are in the range of CLs of acidity for the same region of the Russian Arctic, which were published in (Bashkin and Priputina 2010).

The calculated values of CL of nutrient nitrogen averaged 140–350 eq ha^{-1} yr^{-1} or 2–5 kg N ha^{-1} yr^{-1} (Fig. 3) that is similar to empirical CL for Arctic ecosystems of USA

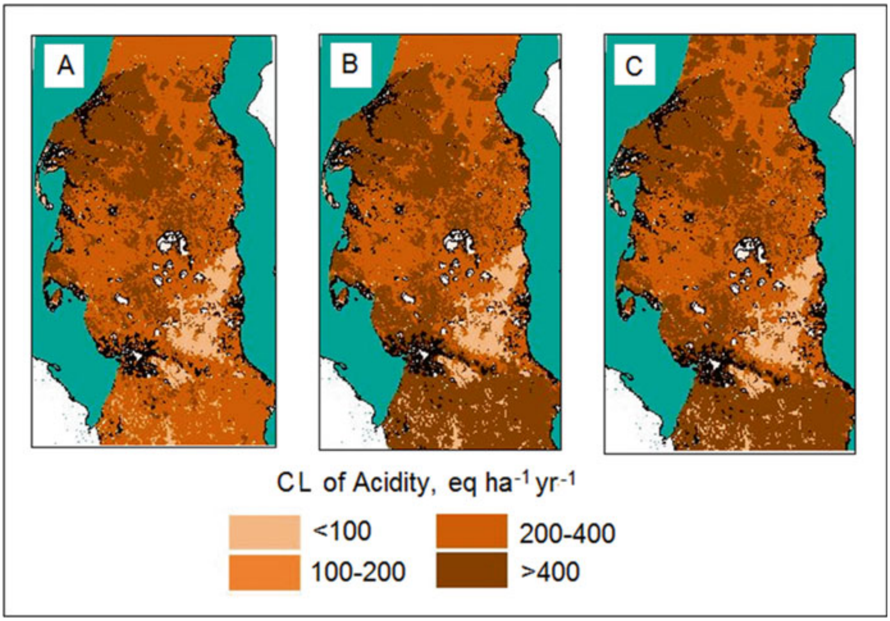


Fig. 2 Critical loads of acidifying compounds for terrestrial ecosystems in the Yamal Peninsula: central (**b**)—conservative climate, left (**a**)—cooling, right (**c**)—warming

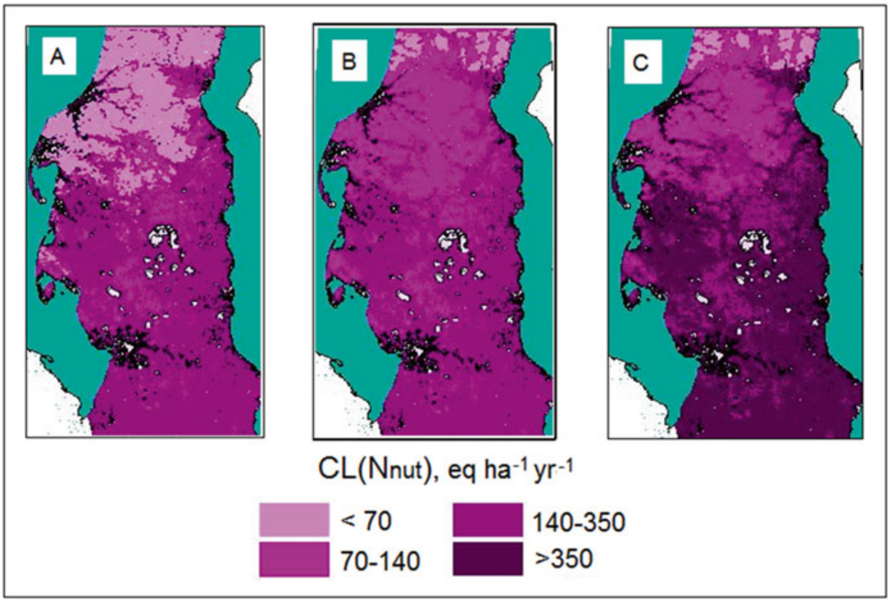


Fig. 3 Critical loads of nutrient N (eutrophication) for terrestrial ecosystems of the Yamal Peninsula: central (**b**)—conservative climate, left (**a**)—cooling, right (**c**)—warming

(Pardo et al. 2015). Values calculated in this study are slightly below the data from similar ecosystems in Western Europe (5–10 kg N ha^{-1} yr^{-1}) that may be associated with more severe climatic conditions of the Yamal Peninsula. Values of CLs below 140 eq ha^{-1} yr^{-1} have been defined for ecosystems in lichen and lichen-moss-herbaceous tundra varying degrees of disturbance and characterized by low productivity of phytocenoses and, as a consequence, the reduced parameters of the removal of nitrogen with the production of biomass and immobilization of nitrogen in soil organic matter.

3.3 Influence of Climate Change on the N Mass Balance and CLs

A possible result of climate cooling or warming will not only change the average annual air temperature and soil strata, but also of the complex of the parameters of the mass balance of nitrogen and macronutrients in terrestrial ecosystems of the Yamal Peninsula, which are dependent on the temperature conditions. Increase-decrease in temperature will affect the intensity of these landscape and biogeochemical processes:

- ecosystem productivity and the fixation of nitrogen and cations in the biomass,
- the intensity of soil weathering cations,

- the rate of immobilization of nitrogen in soil,
- intensity hydrochemical runoff from catchment areas and, accordingly, removal of nitrogen and macronutrients with seeping moisture,
- the rate of denitrification.

According to the proposed scenarios, the cooling climate will be accompanied by a decrease in the next 25 years current average annual temperatures at 2 °C. The proposed scenario of climate warming corresponds to a temperature increase on 1 °C over the same period.

The productivity of tundra phytocenoses largely limited by temperature conditions. Therefore, changes in temperature in accordance with the proposed scenarios will be manifested in the decrease/increase NPP. Calculations, based on Leith (1975), show that the decrease in average temperatures to 2 °C leads to lower values of NPP. As a result, values of removal of nitrogen and macronutrients with biomass growth will be reduced on average by 20 % compared with the conservative scenario. In the case of annual temperature increase by 1 °C the similar settings have 11–12 % of growth. Taking into account calculated for the conservative scenario of the values of N_{upt} as 0.5–3.5 eq ha^{-1} yr^{-1}, changes to this pool of nitrogen will be 0.05–0.4 kg N ha^{-1} yr^{-1} depending on the type of the ecosystem.

Soil weathering characterizes their capacity to neutralize the acid component of precipitation and organic acids formed during mineralization of plant litter. According to De Vries (1993), the rate of BC weathering depends linearly on temperature and soil texture. The calculated values of the change rate of weathering are accounted for soils on sandy deposits 3–10 eq ha^{-1} yr^{-1}, and for soils loamy and clayey—11–35 eq ha^{-1} yr^{-1}. Thus, CL maximum change of acidity in connection with the temperature increase of 1 °C will not exceed 0.5 kg N ha^{-1} yr^{-1}.

Estimate of the rate of immobilization of nitrogen in tundra soils will be very difficult, because the decrease/increase of average temperatures will result in a corresponding change of two opposite processes: the formation and mineralization of organic matter. For the conservative scenario is considered that the N_{im} value is 0.3–0.5 kg N ha^{-1} yr^{-1} depending on productivity of ecosystems; provided $N_{im} < N_{upt}$. Given the decline in ecosystem productivity in scenario when the temperature is lowered, the value of N_{im} can be taken equal to 0.2–0.5 kg N ha^{-1} yr^{-1}, with increasing temperature the magnitude of immobilization will remain at a conservative scenario.

The territory of the Yamal Peninsula is characterized by high moisture and significantly swamped. According to Bobrovitskaya (2007), increasing the temperature by about 1 °C over the last 100 years has led to a corresponding increase in the mean precipitation at 100–115 mm, which can be used in the proposed scenarios. Together with a decrease/increase of average temperatures will change the values of evapotranspiration. If we assume that the resulting flow infiltration of precipitation will decrease/increase by 50–100 mm, the values of the parameter $N_{le(acc)}$—allowed leaching of nitrogen is expected to remain unchanged compared with the conservative scenario on average 10–35 kg N ha^{-1} yr^{-1}. The rate of flow of critical alkalinity leaching will change 10–50 kg N ha^{-1} yr^{-1} depending on the type of the ecosystem. Changing the parameters of denitrification amounted to 3–5 kg N ha^{-1} yr^{-1}.

Against acid effects we are obtained the following picture of possible changes in the quantities of CL acidity with decreasing average annual temperatures at 2 °C. The background of the CL values will remain equal to 200–400 eq ha^{-1} yr^{-1}. The coldness, by reducing the intensity of soil weathering of cations and reduction of the flow of critical alkalinity will decrease the buffering capacity of ecosystems in the southern part of the Peninsula—the main habitat of moss-shrubs tundra. The decrease of acid potential for these ecosystems will be about 100 eq ha^{-1} yr^{-1}. Thus, the proportion of territories, for which the values of CL acidity correspond to 400–600 eq ha^{-1} yr^{-1} will be markedly reduced. Regarding eutrophication, effects of lowering the temperature to 2 °C will have an impact primarily on the most Northern lichen and moss-lichen tundra ecosystems. If, in accordance with the conservative scenario CLs of nutrient nitrogen to these ecosystems are of 1.5–2 kg N ha^{-1} yr^{-1}, while in cold weather their resistance to the processes of eutrophication is reduced to 1–1.5 kg N ha^{-1} yr^{-1}. A rise in temperature of 1 °C will affect the resilience of ecosystems to acid component of precipitation in the Northern sub-Arctic area.

References

Archegova, I. B., & Tsypanova, A. N. (1968). On the issue of migration of iron and organic matter in the soils of the East European tundra. In I. B. Archegova (Ed.), *Chemistry, genesis and cartography of soils* (pp. 32–36). Moscow: Nauka Publ. House.

Bashkin, V. N., Priputina, I. V., Maklyuk, O. V., & Tankanag, A. V. (2009). Ecological substantiation of regional standards of anthropogenic pollutants. *Science and Technology in the Gas Industry, 2*, 33–40.

Bashkin, V. N., & Priputina, I. V. (2010). *Management of environmental risks at emission of pollutants*. Moscow: Gazprom VNIIGAZ Publ. House. 185pp.

Bazilevich, N. I. (1993). *Biogeochemistry of natural zones of USSR*. Moscow: Nauka Publ. House (in Russian).

Bobbink, R., & Hettelingh, J.-P. (Eds.). (2011). *Review and revision of empirical critical loads and dose-response relationships*. Coordination Centre for Effects. RIVM, www.rivm.nl/cce.

Bobrovitskaya, N. N. (2007). *Current state of climate change and its consequences (on the example of the Russian Federation area and with reference to the Yamal Peninsula)*. St. Petersburg: GGI Publ. House (in Russian).

Bogatyrev, L. G. (1976). Some features of the biological cycle in tundra ecosystems in the Western Taimyr. In *Soils and productivity of plant communities* (pp. 24–35). Moscow: Publishing House of Moscow State University (in Russian).

Borinevich, V. A., Konyushkov, N. S., Larin, I. V., Minina, I. P., et al. (1963). *Natural hayfields and pastures*. Moscow-Leningrad: Sel'khozizdat (in Russian).

De Vries, W. (1993). Soil response to acid deposition at different regional scales. Ph.D. thesis, Agricultural University Wageningen, Wageningen, The Netherlands.

Dobrovolsky, G. V. (Ed.). (1979). *Soils of USSR*. Moscow: Mysl' Publ. House (in Russian).

Dobrovolsky, V. V. (1967). *Geography of soils*. Moscow: Prosveshenie Publ. House (in Russian).

Gerasimova, M. I. (1987). *Geography of soils of USSR*. Moscow: Vysshaya shkola. in Russian.

Hall, J., Ullyett, J., Hornung, M., Kennedy, F., et al. (2001). *Status of UK critical loads and exceedances. Part 1—Critical loads and critical loads maps: Update to January 1998 report*. Report prepared under DEFRA/NERC Contract EPG1/3/185. http://critloads.ceh.ac.uk.

Hole, L. R., Christensen, J., Forsius, M., Nyman, M., et al. (2006). Sources of acidifying pollutants and Arctic haze precursors. In: *Acidifying pollutants, Arctic haze, and acidification in the Arctic*, 2–10. Oslo, Norway: Arctic Monitoring and Assessment Programme (AMAP).

Ineson, P., Dutch, J., & Killham, K. S. (1996). *Nitrogen critical loads: Denitrification*. ITE final report to DOE 1996. Grange-over-Sands, UK: Merlewood Research Station.

Kolosova, L. N. (Ed.). (1980). *Atlas*. Moscow: Main Department of Geodesy and Cartography.

Leith, H. (1975). Modelling the primary productivity of the World. In: H. Leith, & R. H. Whittaker (Eds.), *Primary productivity of the biosphere. Ecological studies* 14. NY: Springer-Verlag.

Pardo, L. H., Robin-Abbot, M. J., Fenn, M. E., Goodale, C. L., et al. (2015). Effects and empirical critical loads of nitrogen for ecoregions of the United States. In: De Vries, W., Hettelingh, J.-P., Posch, M. (Eds.). *Critical loads and dynamic risk assessments: nitrogen, acidity and metals in terrestrial and aquatic ecosystems*. doi:10.1007/978-94-017-9508-1.

Parinkina, O. M. (1978). The decomposition of plant litter and fiber in the Taimyr tundra. *Eurasian Soil Science, 11*, 47–55 (in Russian).

Peive, Y. V. (1961). *Soil biochemistry*. Moscow: Selkhozidat Publ. House (in Russian).

Saneev, B. G., Lagerev, A. V., & Khanaeva, V. N. (2015). Development of Russian gas market in the long term: The role of the Asian region. *GAS Industry of Russia, 8*(726), 14–18.

UBA. (1996). *Manual for methodologies and criteria for mapping critical levels/loads*. Text 71, UBA, 1996.

UBA. (2004). *Manual on methodologies and criteria for modelling and mapping critical loads and levels and air pollution effects, risks and trends*. Chapter 5.5. www.icpmapping.org.

Vasilevskaya, V. D., Grigor'ev, V. Y., & Pogozhaeva, E. A. (2006). Relationships of soil-vegetation characteristics in tundra as indicators of ecosystem sustainability, degradation and recovery. *Eurasian Soil Science, 3*, 352–363 (in Russian).

Possible Indicators for Assessing Geo-Environmental Risk in Polar Ecosystems of the Yamal Peninsula in Relation to Pollutant Emission During Gas Production

Vladimir N. Bashkin, Irina V. Priputina, and Arina V. Tankanag

Abstract The methodologies of risk analysis and critical loads (CLs) have been used to assess the influence of anthropogenic emission of NOx on terrestrial ecosystems of the Yamal Peninsula in the impacted zone of Bovanenkovo gas condensate field (BGCF). Depending on dominant plant communities, the calculated values of CLs of nutrient nitrogen were equal in average 210–350 eq ha^{-1} yr^{-1} (or 3–5 kg N ha^{-1} yr^{-1}). Mean values of CLs of acidity were lower (100–200 eq ha^{-1} yr^{-1}). Additional N deposition, associated with emission of NOx, is estimated at the center of 30-km zone under impact in 35–140 eq ha^{-1} yr^{-1} (or 0.5–2 kg N ha^{-1} yr^{-1}) at the initial stage, and more than 2000 eq ha^{-1} yr^{-1} (or 25–30 kg N ha^{-1} yr^{-1}) at maximum gas production. But even at high exposure, exceedance of CLs in most ecosystems of this territory will not be higher than 1.5–2 kg N ha^{-1} yr^{-1} that corresponds to low risks of eutrophication.

Keywords Yamal Peninsula • Bovanenkovo gas condensate field • NO_x emission • Ecosystem eutrophication • Risk estimation

V.N. Bashkin (✉)
Institute of Physicochemical and Biological Problems of Soil Science of Russian Academy of Sciences, Pushchino, Moscow Region 142290, Russian Federation

Institute of Natural Gases and Gas Technologies—Gazprom VNIIGAZ LLC, Razvilka, Moscow Region 142719, Russian Federation
e-mail: bashkin@issp.serpukhov.su

I.V. Priputina
Institute of Physicochemical and Biological Problems of Soil Science of Russian Academy of Sciences, Pushchino, Moscow Region 142290, Russian Federation

A.V. Tankanag
Institute of Cell Biophysics of Russian Academy of Sciences, Pushchino, Moscow Region 142290, Russian Federation

V.N. Bashkin (ed.), *Biogeochemical Technologies for Managing Pollution in Polar Ecosystems*, Environmental Pollution 26, DOI 10.1007/978-3-319-41805-6_11

1 Introduction

The relevance and significance of issues of environmental conservation of natural resources development of the Russian Far North, which ecosystems are characterized by low potential of resistance to external anthropogenic influences, it is now generally accepted. The priority object of the mastering is Bovanenkovo group of hydrocarbon deposits (BGCF), located in the Western part of the Yamal Peninsula (Fig. 1) and is characterized by large reserves of natural gas and condensate (Samsonov et al. 2007).

Fig. 1 Major hydrocarbon deposits of Peninsula Yamal (Samsonov et al. 2007)

The Bovanenkovo gas-producing complex is located in the Western part of the Yamal Peninsula on the territory of the Yamal district of the Yamal-Nenets Autonomous Okrug of the Tyumen region. The climate is sub-Arctic: winter is long and cold, summer is cool with frequent night frosts.

2 Characterization of the Impact Zone of the Bovanenkovo Gas Condensate Field

This conducts qualitative and quantitative analysis of systematic emission of contaminants (pollutants) that are formed during the operation of the main processing facilities of Bovanenkovo gas condensate field (BGCF), located on the Yamal Peninsula. Sources of emissions are tied geographically. The term "systematic release" below refers to the minimum possible (inevitable) emission of pollutants into the environment during stationary operation of a particular object or its component parts referred to and justified by the project.

2.1 The Composition of the Bovanenkovo Gas Condensate Field

Two powerful multilayer complexes occurring at depths of 530–3015 m represent the productive section of the BGKM. The Senoman-Apt terrigenous complex contains gas deposits, the Neocomian-Jurassic—gas-condensate deposits. On the southern dome of the reservoir some layers contain an oil rim. Gas composition of various field geological layers is shown in Table 1.

Table 1 Gas composition of various field geological layers

Compound	Senoman layer, % vol.	Neocom-Yura layer, % vol.	
		First part	Second part
Methane	99.04	96.37	90.918
Ethan	0.028	2.89	5.015
Propane	0.007	0.05	1.710
Carbon dioxide	0.063	0.22	0.307
Nitrogen	0.65	0.43	0.016
Bhutan	–	–	0.744
The density under normal conditions, kg/m^3	0.674	0.690	0.782

Holing of the field provides for producing shrubs directional wells. It is expected to about 750 drilling wells, grouped by 56 bushes: in the Northern zone 22 bushes—300 wells in the southern zone on the 34 bushes—450 wells. From the wells to the units of complex preparing the gas (UCPG), comprehensive training gas is fed through the system of prefabricated aboveground piping. The project envisages the construction of three UCPGs, production bases, construction camps. Besides these objects, there are also others related to the railway to BGCF. The total number of transport units will be more than 200.

2.2 Air Pollution

All kinds of technological objects emitted into the atmosphere pollutants proposed to be divided into two categories: ongoing (long-term) current and temporarily (briefly) acting. The first should include the sources of heat and electricity, roads, compressor stations and other facilities for economic and industrial purposes. The second type—the objects on which there was an emergency situation (or is planned episodic purging) with the emission of pollutants into the atmosphere (Gritsenko et al. 2009). Among the possible sources of air pollution of this type include:

- emergency gas emissions occurring in the process of drilling, and when the destruction of pipelines, vessels, apparatuses;
- leakage from valves, flange connections of technological equipment;
- improper storage of chemicals and petroleum products;
- replacement of explosive natural gas pipelines and vessels in inert gases with discharge products of substitution in the atmosphere.

2.3 The Initial State of the Atmosphere

Data on air pollution are based on the information about the pollution of atmospheric precipitation and in the first place—snow cover. The concentration of sulfur in the ambient air of the North of Western Siberia is about 2.0 $\mu g\ m^{-3}$. The average annual salinity of atmospheric precipitation in the Peninsula of Yamal is 15 $mg\ l^{-1}$, average annual concentration of chloride ions in precipitation is 3 $mg\ l^{-1}$, sulfate ions to 4 $mg\ l^{-1}$. The total number of substances falling with precipitation on the earth's surface is 50 $kg\ ha^{-1}\ yr^{-1}$. Arctic regions are characterized by a low content of aerosols in ambient air due to the presence of a large number of wetlands and high water cut areas (Dobrovolsky 2003).

2.4 Brief Description of Pollutants

The main pollutants in the atmosphere during operation of the gas facilities of the complex are carbon monoxide (CO), nitrogen oxides (NO, NO_2), hydrocarbons and carbon black (soot). To buster station the main pollutants of the first category of danger of the power output, and volume of the annual gross emissions are oxides of nitrogen. Table 2 shows the total NO_x emissions in different sources.

The main sources of NO_x emissions on BGCF are busters and gas turbine power plant. They account for over 80 % of all emissions of oxides of nitrogen. The NO_x emissions from heating sources account for 15–16 % and 4 % for random (instantaneous) emissions from purging of wells and emissions from automotive vehicles.

3 Environmental Risk Assessment in the Zone of Influence of Emissions of NO_x from the BGKM

Environmental risk assessment for ecosystems in the impacted zone of BGCM is performed according to a standard algorithm (Fig. 2).

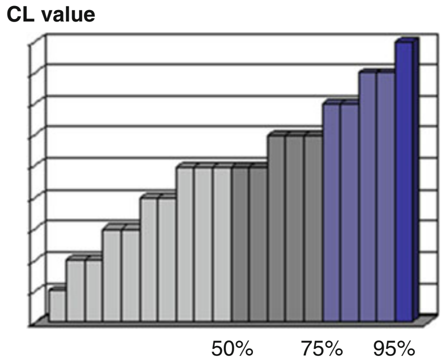
Step 1: Hazard identification. According to the plans of the BGCF development, the field will be developed in phases, with the serial input of the technological objects that will affect the dynamics of the intensity of emission of pollutants. In the general structure of the atmospheric emission methane, carbon dioxide and oxides of nitrogen are dominated (Bashkin 2014). The most significant risk factor for the regional ecology of the Western Yamal Peninsula will be increasing release of anthropogenic nitrogen compounds into the environment. Their excess, apart from the direct risks of toxicity to biota due to high concentrations of NO_x in the air, can determine the complex of indirect (secondary) environmental risks associated with eutrophication and acidification.

Table 2 Gross emissions performance PC on objects BGCF

Technological units	Emission of NO_x, $g\ s^{-1}$	Total emission of NO_x, $g\ s^{-1}$	%
Unit 1—heat supply	48.72 13.29	62.01	24.16
Unit 2—heat and electricity supply	89.32 8.48 29.1	126.9	49.44
Unit 3—heat supply	40.6 13.29	53.89	21.0
Railway station	4.62	4.62	1.8
Transport	6.34	6.34	2.47
Wells	2.92	2.92	1.13
Total		256.68	100

- Calculation of drilling conducted on the assumption of four-time purging of wells for the period of operation

Fig. 2 Cumulative curve of possible values of CLs for an ecosystem



Species diversity of plant communities in the BGCF impacted zone is determined by the complexity of the combination of vascular species, mosses and lichens. The basis of the lichen biota are epigeal species (84 %), but their wide distribution is limited due to significant wetlands, and permanent grazing deer in previous years. This has led to the fact that forage lichen species were replaced by low edible kinds. Grass species, sedges, shrub willow and mosses are predominant in reindeer pastures. As a result of overgrazing part of the ecosystems of the studied area has sparse or severely disturbed vegetation, which reduces the productive resources of biomass. Potential recipients in terms of exposure to emissions of nitrogen oxide will be terrestrial lichen species, mosses, main vascular plant species, as well as soil algal flora, which in tundra soils have the main pool of the biological fixation of atmospheric nitrogen.

Step 2: *Estimation of dependence "dose-response" (calculation of critical loads (CLs))*. According to the proposed algorithm for the assessment of environmental risks, determining acceptable (reference) dose exposure to nitrogen oxides on plant communities in the BGCF impacted zone was conducted using probabilistic methods of CL calculation for the effects of eutrophication and acidification ($CL(N)_{nut}$ and CL acidity). The CL calculations performed with detailed spatial resolution of 1 × 1 km. The variable parameters of the equations of mass balance were: the flow of cations and anions from atmospheric deposition; soil cations weathering; nitrogen and cation uptake in the production of terrestrial biomass; immobilization of nitrogen in soil organic matter in tundra and boggy tundra soils. For each ecosystem, using the Monte-Carlo method was calculated from a random sample of 1000 possible values of CLs. Subsequent testing showed that such a large number of "runs" with all the randomness of the samples provides high repeatability of results. Then from the obtained cumulative distributions of likely values of CLs were selected values corresponding to 50 %, 75 % and 95 % confidence level (Fig. 2), which in ArcView software environment were constructed corresponding maps.

Depending on the nature of plant communities and dominant species the calculated values of nitrogen CL on the effects of eutrophication are (Fig. 3): for 50 % of the level of probable $CL(N_{nut})$ values—210–350 eq ha^{-1} yr^{-1}; for a 75 % level—210–700 eq ha^{-1} yr^{-1}; 95 %—210–840 eq ha^{-1} yr^{-1}. The obtained values correspond

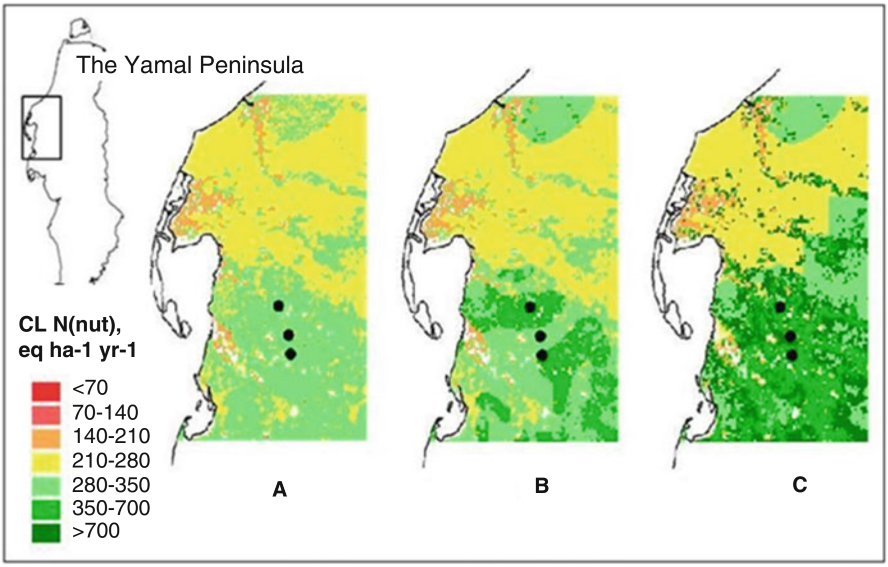


Fig. 3 The spatial distribution of ecosystems with different values of CLs of nutrient nitrogen: left map (**a**)—50 % level of CLs, central (**b**)—75 %, right (**c**)—95 %

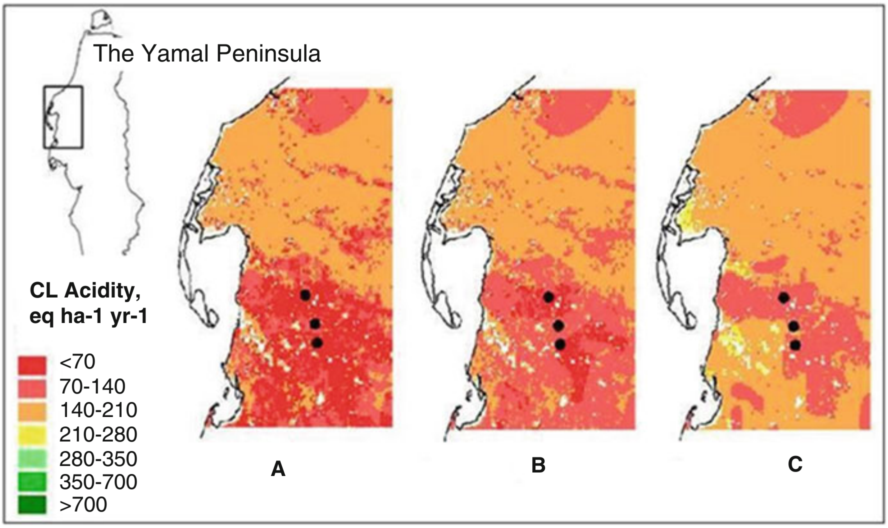


Fig. 4 The spatial distribution of ecosystems with different values of CLs of acidity: left map (**a**)—50 % level of CLs, central (**b**)—75 %, right (**c**)—95 %

to a valid entry with atmospheric deposition from 3–5 to 10–12 kg N ha^{-1} per year, which is higher than the currently available indicators of atmospheric supply of nitrogen.

The obtained values of CL acidity (Fig.4) reflect characteristic reduced potential of tundra ecosystems in the tolerance to acid component of atmospheric deposition. According to conservative estimates (50 % probability values), the calculated values of CL acidity in 30 km zone from the BGCF objects are according to the acceptable intake of 50–100 eq ha^{-1} yr^{-1} acid-forming compounds. The values of CLs at 75 % and 95 % probabilities, are higher, but do not exceed the value of 280 eq ha^{-1} yr^{-1}, which is comparable to the flow of about 3.5–4 kg of sulfur and/or nitrogen and corresponds to the modern values for the total supply of these elements from atmospheric deposition.

Step 3: *Exposure assessment*. Scenarios of emissions of nitrogen oxides from BGCF technological systems match their phase input according to the plans of field development. Assessment of levels of nitrogen inputs to terrestrial ecosystems from atmospheric deposition is performed using a model of NO_x dispersion from a point source (UCPG) based on data from the cumulative emissions of NO and NO_2. Polygons of 1 × 1 km spatial resolution are correspond to the polygons in the model of CLs calculation. The results are presented in Fig. 5.

As follows from simulation data, after the phased commissioning of the BGCF process facilities regional background atmospheric supply of nitrogen will increase. The main impact will affect the 30 km zone. In the first years after entering process-

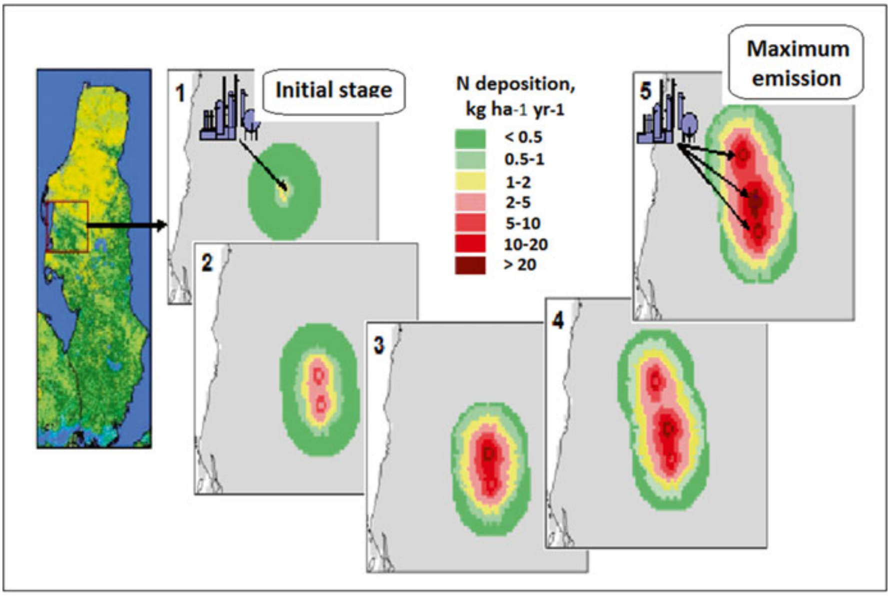


Fig. 5 Nitrogen deposition in ecosystems of BGKM at different operational stage

ing facilities of UGCF 1 and UGCF 2, the level of additional nitrogen deposition for this zone is estimated at 35–140 eq ha^{-1} yr^{-1}, which corresponds to a flow of 0.5–2 kg N ha^{-1} yr^{-1}. Subsequently, increases in emissions of nitrogen oxides after the commissioning of UCPG 3, the greatest impact may be more than 2000–2500 eq ha^{-1} yr^{-1} (or 30–35 kg N ha^{-1} yr^{-1}), which are comparable to the rate of deposition, which is characteristic for industrial and urbanized areas. At the maximum emissions nitrogen anthropogenic deposition on the periphery of the considered 30 km zone will be 2–5 kg N ha^{-1} yr^{-1}.

Step 4: *Risk characterization*. The results of calculations of the ecological risks to terrestrial ecosystems due to eutrophication are shown in Fig. 6. At all stages a large part of this territory is characterized by the absence of exceedances of $CL(N_{nut})$, designed for the most sensitive to nitrogen pollution of oligotrophic species of lichens and mosses. High risks of eutrophication are projected to ecosystems near BGCF after commissioning of booster compressor stations.

At the maximum level of emissions exceeding $CL(N_{nut})$ will be reliably for almost the entire 30-km zone of influence, with what will be associated changes in the structure of the vegetation cover of this area due to the death of the lichen species and mosses, as well as the disappearance of some oligotrophic vascular species (Bashkin and Priputina 2010). The most likely effect of eutrophication of ecosystems in this area will increase the number of sedges and grasses and increasing the overall productivity of phytocenoses, which can lead to changes in thermal characteristics of the soil-vegetation layer. Another environmental effect of increasing

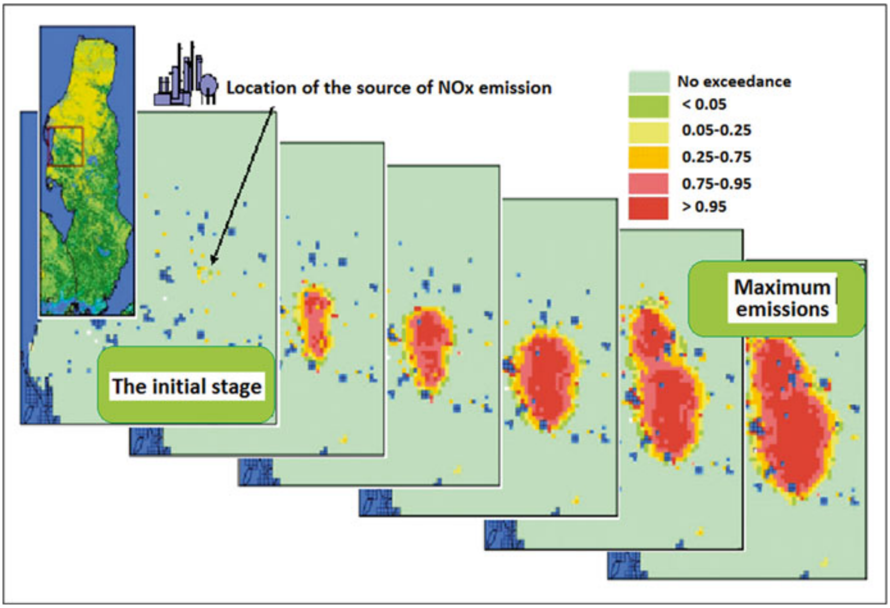


Fig. 6 Risks of ecosystem eutrophication in the BGCF impacted zone at different operational stages (%)

atmospheric supply of anthropogenic nitrogen compounds in the area of maximum impact is to increase the acidity of soil and of ground and surface waters. Given the fact that the bulk atmospheric deposition of nitrogen in the given territory shall be deposited in the snow cover, it is possible to predict the removal of a part of the "excess" nitrogen compounds with melting waters from terrestrial ecosystems to the local water bodies (Safonov et al. 2009). Thus, the "actual" load of nitrogen in the resulting exposure of ecosystems in BGCF emissions will be approximately about 50 % of the model values of deposition.

When modeling the deposition was not taken into account the (relatively small) part of the emissions of nitrogen oxides, which is included in the global dispersal processes in the atmosphere, which will increase total regional background deposition of nitrogen on the territory of the Yamal Peninsula. Taking into account the obtained data, the increase in the atmospheric supply of nitrogen from the contribution of emissions of the Bovanenkovo gas condensate field on a regional scale should not exceed 1–1.5 kg N ha^{-1} yr^{-1}, which will not lead to a substantial increase in environmental risks in relation to the effects of eutrophication.

References

Bashkin, V. N., & Priputina, I. V. (2010). *Management of environmental risks at emission of pollutants*. Moscow: Gazprom VNIIGAZ Publ. House. 185pp.

Bashkin, V. N. (2014). *Biogeochemistry of Polar ecosystems in gas industry impacted zones*. Moscow: Gazprom VNIIGAZ. 302 pp.

Dobrovolsky, V. V. (2003). *Fundamentals of biogeochemistry*. Moscow: Academia. 400pp.

Gritsenko, A. I., Maksimov, V. M., Samsonov, P. O., & Akopova, G. S. (2009). *Ecology: Oil and gas*. Moscow: Akademkniga Publ. House. 680pp.

Safonov, V. S., Volkov, A. N., & Kovalev, S. A. (2009). *Substitution of criteria of negative impacts of gas compressor station on population and environment*. Moscow: VNIIGAZ Publ. House. 72pp.

Samsonov, R. O., Kazak, A. S., Bashkin, V. N., & Lesnykh, V. V. (2007). *System analysis of geoecological risks in gas industry*. Moscow: Nauchniy Mir Publ. House. 271pp.

Analysis of Geoecological Risks and Ratings as a Factor of Improving Investment Attractiveness of Enterprises

Olga P. Trubitsina and Vladimir N. Bashkin

Abstract The article is devoted to the issues of improving investment attractiveness of enterprises through the analysis of geo-ecological risk (GER) and ratings. The authors reveal the necessity of using these approaches, given contemporary investment climate in Russia. Special attention is paid to the environmental ratings as the elements of the system of corporate responsibility. Also the authors suggest using the concept of GER analysis on the example of oil and gas enterprises in the Russian Arctic. As for investing, the main advantage of this concept is making the most effective investment management decisions based on quantitative estimates of the GERs magnitude, determination of their likelihood, especially in the areas with low information availability and a high degree of uncertainty.

Keywords Geo-environmental risk • Environmental rating • Investment attractiveness of enterprises • Oil and gas industry • The Arctic

1 Introduction

The world is known for its striving towards the sustainable development. According to the United Nations Conference on Trade and Development (UNCTAD) (Global Investment Trade Monitoring 2015) in order to achieve the intended goal, the "international system of investment management needs to be reformed". Global flow of foreign direct investment (FDI) has decreased by 8 % in 2014 to $1.26 trillion.

O.P. Trubitsina (✉)
Northern (Arctic) Federal University, North Dvina Bank, 17,
Arkhangelsk 163002, Russian Federation
e-mail: test79@yandex.ru

V.N. Bashkin
Institute of Physicochemical and Biological Problems of Soil Sciences of Russian Academy of Sciences, Pushchino, Moscow Region 142290, Russian Federation

Institute of Natural Gases and Gas Technologies—Gazprom VNIIGAZ LLC,
Razvilka, Moscow Region 142719, Russian Federation

V.N. Bashkin (ed.), *Biogeochemical Technologies for Managing Pollution in Polar Ecosystems*, Environmental Pollution 26, DOI 10.1007/978-3-319-41805-6_12

However, this figure changes non-uniformly in different countries. Thus, while FDI has increased in Europe by 36 % compared to the last year, it also showed a 70 % drop in Russia, which is linked to regional conflicts, introduction of sanctions, and decrease in commodity prices (Global Investment Trade Monitoring 2015).

Stimulation of investment activities in Russia under current conditions is instrumental for increasing the national economic activity, integration into global economy and financial market (Strizhova 2015).

Sectors of economy related to exploitation of natural resources and having a good export potential (including oil and gas industry) (Official Site 2016) are seen by foreign partners as the most attractive sectors of economy for investing. Therefore, GER analysis and voluntary submission of reports as part of raising the environmental awareness of business are paramount in boosting the investment appeal of enterprises in this industry.

This article focuses on certain points of methods, used to assess the outside of investment appeal of an enterprise, in particular: (1) the use of existing assessment results, provided by credit rating agencies, leading magazines, etc.; (2) drawing a conclusion based on GER analysis (case study: oil and gas producers in the Russian Arctic).

2 The Role of Ecological Ratings in Raising the Environmental Awareness of Business

Quantitative assessment of investment appeal of an enterprise presumes that the environmental performance stands out among other supposed parameters and that it is assessed mainly in terms of fines for environmental law violations. The generalizing factor is calculated as a ratio of fines for environmental law violations to net profit. Zero shall be preferred value for this figure. However, it is no less important to take into account conservation and environmental protection activities of an enterprise as part of its short-term and long-term planning. The interaction of economics and ecology brings up new vision of cost estimate and internalization, i.e. the need to consider external impact on the environment in enterprises' financial reports.

It is not uncommon to assess investment appeal of the whole industry before proceeding to assessment of individual enterprises. In such a case, the following will be assessed: various features, properties, assets, and possibilities of the industry, which define the demand for capital formation investments within specific industry sectors (Trubitsina 2014).

Environmental ratings affect the market, concerned in financial outcome, in such a way, that they provide unbiased evaluation of technologic aspect of production. The new service market is currently emerging in Russia—providing of information on environmental performance of companies and enterprises. As the lack of unbiased data in this field is made up for, it will allow for more effective application of environmental criteria to investment, equipment, goods, and service markets (Avramenko et al. 2006).

Late 1990s marked the development of environmental ratings as part of raising the environmental awareness of business strategy in order to find the best in terms of their investment appeal. So in 1997 the Global Reporting Initiative (GRI) was established with the trinity of economic, social, and environmental performance of a company as its manifest. This is the voluntary international standard for companies, which report on sustainable development. However, unlike ISO 14000 compliance certificates, which are all but mandatory for companies with big claims for good market positions, the GRI is aimed more at increasing the investors' confidence in reporting companies, improving their goodwill, and cost reduction through new business opportunities. GRI is not yet common in Russia; however, some of the largest Russian corporations perceive participation in World Business Council For Sustainable Development (WBCSD) as a key instrument in promoting their influence on the global market (Trubitsina 2014).

The Dow Jones Sustainability Indices (DJSI) launched in September 1999, are a family of international indices evaluating the sustainability performance of businesses, which, as of 2015 (DJSI 2015), includes a total of 3470 companies seeking sustainable development. The rating is based on uniform analysis of various corporate economic, environmental, and social performance (Trubitsina 2014). As far as the environmental performance is concerned the key change of 2015 as compared to the last year is the "shift of attention towards efficiency of environmental management system" (DJSI 2015)—a branch of management, aimed at environmental performance, fulfillment of mandatory requirements, and assessment of risks and possibilities (The International Standard 2015).

An enterprise shall be capable to produce the expected results from the implemented environmental management system, prevent or mitigate the unwanted effects, as well as provide for continuous improvements. It can be guaranteed by assessment of risks and possibilities, linked to environmental performance, compliance obligations, and other issues, demands, and expectations of the concerned parties, including investors.

Although risks and possibilities, as well as their assessment procedure, shall be identified, ISO 14001:2015 does not specify requirements for formal risk management or documented risk management procedure. Methods of risks and possibilities assessment as usual are at the discretion of company. These methods may be either plain qualitative assessment or more complicated ones involving quantitative indices depending on the company's profile. The identified risks and possibilities represent a reference point for planning, setting of environmental goals (The International Standard 2015) and serve as benchmarks for investors.

Therefore, the introduction of environmental ratings has made it possible to prioritize attracting of investments to those companies, which the most meet the sustainable development criteria. The growing interest of investors (both institutional and private) towards ratings provokes companies to view them as a drive to continuously improve their internal environment.

3 GER Analysis (Case Study: Oil and Gas Producers in the Russian Arctic)

As far as attracting investments to businesses involved in exploitation of natural resources, GER indices are defined as risks occurring in the “industry-environment” system stemming from reciprocal impact of industrial plants and the environment (Bashkin 2014). GER assessment represents the nature and extent of this reciprocal interaction of anthropogenic and natural forces, helping to acknowledge them and make efficient investment decisions.

The activity in the petroleum and natural gas industry in the Arctic Zone of the Russian Federation (AZRF) has been on the increase for the past several years and the GERs have been growing accordingly. It results in the formation of “hot spots” and “impact areas” characterized by a high level of chemical contamination of the environment and transformation of the natural geochemical background, degradation of marine life, vegetation, soils, uncontrolled development of erosion, cryogenesis, formation of sinkholes across vast areas, introduction of contaminants to food chains, high disease rates among the population, air being polluted with strontium compounds, heavy metals (particularly mercury), petroleum products, etc. (Diagnostic Analysis 2011).

Expansion of oil and gas development projects, especially offshore, can aggravate this situation, in particular from acid-forming pollutants in the implementation of the programs for the extraction of hydrocarbons. In this regard, and taking into account transboundary pollution (circumpolar transport of pollutants from the West) in the AZRF requires monitoring of acid deposition as a component of a unified system of environmental monitoring. Its realization must be accompanied by a quantitative assessment of GER the acidification and eutrophication of terrestrial and marine ecosystems on the basis of international approaches to the calculation of critical loads (CL) using already established international methodological approaches (Bashkin and Priputina 2010; Posch et al. 2007; UBA 2004), and results of previous research, some of which are cited in the referenced sources (Bashkin 2006, 2014; Bashkin and Priputina 2010; 2015; Bashkin et al. 2012, 2015; Priputina and Bashkin 2012; Trubitsina and Shvartsman 2007; Trubitsina 2002, 2013, 2015; Markelov et al. 2013; Demidova 2007; Louvar and Louvar 1998; Eduljee 1999; Taneja and Sumiran Satsangi 2003; Porter et al. 2005).

From the point of view of the concept according to (Bashkin et al. 2015, 2016; Bashkin and Priputina 2015), GER is determined as a two-dimensional indicator which characterizes the probability of negative changes developing in the condition of ecosystems as the recipients of impact, and the extent of such changes (Bashkin and Priputina 2010). The quantitative assessment of GER is based on the calculation and dimensional analysis of exceeded CLs for pollutant X (Ex(X)) within an area affected by an industrial site. Exceeded CLs reflect the relation between exposure (actual or forecast pollutant load) and safe impact level (pollutant CL value). It is proposed that the impact on ecosystems should be calculated as the percentage of portions where CLs are exceeded in relation to the total area of a given group of portions (Bashkin and Priputina 2015).

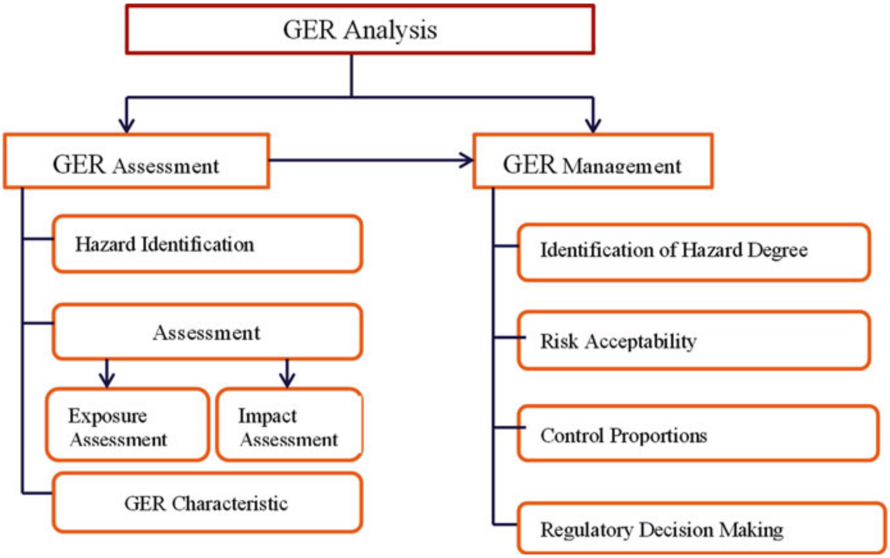


Fig. 1 Scheme for the GER analysis of acid-forming deposition in areas affected by oil and gas industry sites in the Russian Arctic (based on materials of Bashkin et al. 2016)

The calculation of the GERs of acid-forming deposition is proposed using probabilistic modeling of exceeded CLs based on the Monte Carlo method described in the articles (Bashkin and Priputina 2015; Bashkin et al. 2015). In contrast to the traditional calculation of the excess of CLs, arrays of bio/geo/chemical parameter values rather than isolated values (default, or medium) are used as input data for the simulations. Input data arrays can be prepared based on both field survey data and a review of similar projects (Bashkin et al. 2015).

The GER analysis includes risk assessment and management stages (Eduljee 1999). Scheme for the GER analysis of acid-forming deposition in areas affected by oil and gas industry sites in the Russian Arctic is shown in Fig. 1.

In the evaluation GER based on CLs of acid-forming pollutants are initially encouraged to follow a formal procedure of risk assessment. It begins with stage concerning the identification of emission sources, scenarios of man-induced impact, pollutants of the enterprise (including acid-forming), potential impact recipients and its ranking (Bashkin and Priputina 2015; Bashkin et al. 2015).

This is followed by the assessment stage which consists of the exposure assessment and effects. This requires a quantitative estimation of impact based on available information on hazards and recipients (Bashkin et al. 2015). Exposure assessment must include a detailed characteristic of the potential recipient groups, calculating the actual load level of acid-forming pollutants, determining the acid-forming pollutant flows and its boundaries, estimating the exposure concentrations. Impact Assessment also must include some important position. They are determination of the reference doses, parameterization of the reversible and irreversible impacts and detection of the potential stability of ecosystems (Bashkin and Priputina 2015; Bashkin et al. 2015). Next stage is named GER Characteristic which is necessary to calculate of GER for different groups of effects, recipients and exposure scenarios (Bashkin 2007). The GER assessment study must be finalized by reviewing the uncertainty of obtained results. For this purpose, the sources of uncertainty must be described for each risk assessment stage and the accuracy of calculation results must be estimated (Bashkin 2014).

The GER management for acid-forming deposition in areas affected by oil and gas industry is a decision-making procedure aimed to achieve acceptable levels of total GERs associated with existing or future industrial sites. This procedure takes into account GER estimation for acid-forming deposition as well as technological and environmental capabilities of risk prevention, reduction, monitoring, response, communication, etc.

The GER control philosophy must incorporate strategic and tactical objectives. Strategic objectives should reflect the commitment to achieve the maximum possible level of public welfare in general, tactical objectives should pursue an improvement in the safety of all groups of live forms in the Arctic region.

4 Conclusion

The ultimate goal of environmental ratings is to increase the investment appeal of businesses as their environmental awareness grows. Particularly high ratings indicate low environmental risks of the given business. The data (Bashun 2003) on "environmental ratings shows that environmental management alone, even if backed by ISO certificate, is not enough for a business to raise its environmental awareness. The approved environmental policies still need to be implemented, meaning progressive reduction of negative effect on the environment". In this regard and in view of the current investment climate in Russia, as well as given the latest trends of "shifting of attention towards efficiency of environmental management" (DJSI 2015), GER analysis is ever more important in terms of finding a reference point for long-term and short-term planning, as well as for specifying environmental goals and benchmarks for investors.

The proposed GER analysis model (case study: the most investment appealing businesses for foreign partners) allows for quantitative assessment of both the extent of estimated changes to ecosystems, as well as their probability. It provides a detailed profile of an ecosystem as subject to industrial impact. Furthermore, strong interrelation between individual components of land and aquatic ecosystems, as well as the natural variability of parameters characterizing the state of these components, have been considered in this procedure. The findings of GER analysis shall help to make investment decisions in oil and gas industry projects in such areas with poor accessibility of information and high degree of uncertainty as the Arctic Region (Bashkin et al. 2015).

References

Avramenko, A. A., Sanin, S. V., & Vishnyakov, Y. D. (2006). Problems of rating estimation of investment attractiveness of enterprises based on environmental component. *Journal of Russian Entrepreneurship, 4*(76), 96–101.

Bashkin, V. N. (2006). *Modern biogeochemistry: Environmental risk assessment* (2nd ed.). Berlin, London: Springer Publishers. 444pp.

Bashkin, V. N. (2007). *Environmental risks: Calculation, management, insurance: Textbook*. Moscow: Higher Scool. 360pp.

Bashkin, V. N. (2014). *Biogeochemistry of polar ecosystems in impacted zones of gas industry* (p. 302). Moscow: Gazprom VNIIGAZ Publishing House.

Bashkin, V. N., Arno, A. B., Arabsky, A. K., Barsukov, P. A., Priputina, I. V., & Galiulin, R. V. (2012). *Retrospective and forecast of geoecological situation on gas-condensate fields of the far north*. Moscow: Gazprom VNIIGAZ Publishing House. 280pp.

Bashkin, V. N., & Priputina, I. V. (2010). *Management of environmental risks at emission of pollutants*. Moscow: Gazprom VNIIGAZ Publishing House. 189pp.

Bashkin, V. N., & Priputina, I. V. (2015). (Geo)ecological risk assessment in gas industry development scenarios. *Open Ecology Journal, 8*, 65–68.

Bashkin, V. N., Trubitsina, O. P., & Priputina, I. V. (2015). Evaluation of geo-environmental risks in zones of influence of oil and gas industry in the Russian Arctic. *North and Arctic, 19*, 92–98.

Bashkin, V. N., Trubitsina, O. P., & Priputina, I. V. (2016). Evaluation of geo-environmental risks in the impacted zones of oil and gas industry in the Russian Arctic. In V. N. Bashkin (Ed.), *Biogeochemical technologies for managing environmental pollution in polar ecosystems*. NY: Spinger.

Bashun, V. (2003). Ecoratings industrial companies. *The Expert, 42*, 10–16. Available at: http://raexpert.ru/ratings/ecorating/publication1/.

Demidova, O. A. (2007). Critical loads approach in ecosystem risks assessment. *Problems of Risk Analyses, 3*, 50–2.

Diagnostic Analysis of the Environmental Status of the Russian Arctic (Advanced Summary). (2011). Editor-in-Chief: B.A. Morgunov. Moscow: Scientific World, 172pp.

DJSI. (2015). *Review results*. September 2015, RobecoSAM, 32pp. Available at: http://www.sustainability-indices.com/images/review-presentation-2015.pdf.

Eduljee, G. (1999). Risk assessment. In J. Petts (Ed.), *Handbook on environmental impact assessment: 2 volumes* (pp. 374–404). Oxford: Blackwell Science Ltd.

Global Investment Trade Monitoring. Embargo, Report of United National Conference on Trade and Development, No. 18, 29 January 2015, 17:00 GMT (12:00 New York, 18:00 Geneva).

Louvar, J. T., & Louvar, B. D. (1998). *Health and environment risk analysis. Fundamentals and applications*. NJ: Prentice Hall. 678pp.

Markelov, V. A., Andreev, O. P., & Kobylkin, D. N. (Eds.). (2013). *Sustainable development of gas industry*. Moscow: Nedra. 211pp.

Official site of "Federal state statistics service"—The flow of foreign investments by kinds of economic activity. (2016). Available at: www.gks.ru.

Porter, E., Blett, T., Potter, D., & Huber, C. (2005). Protecting resources on federal lands: Implications of critical loads for atmospheric deposition of nitrogen and sulfur. *BioScience, 7*, 603–612.

Posch M., Hetteling J-P., Slootweg J. (2007) Critical loads and dynamic modelling of nitrogen // Critical loads of nitrogen and dynamic modeling. CCE Progress Report 2007. Bilthoven. The Netherlands. 41–51.

Priputina, I. V., & Bashkin, V. N. (2012). Environmental risks related to technogenic pollution: Analysis of approaches and estimation methods. *Problems of Risk Analysis, 5*, 12–25.

Strizhova, Y. S. (2015). Foreign investment in the Russian economy. *Problems of Economics and Management, 1*(01), 9–11.

Taneja, A., & Sumiran Satsangi, G. (2003). Critical load—A new approach, concept and application. *Asian Journal of Experimental Sciences, 1–2*, 23–34.

The international standard ISO 14001:2015. Environmental management systems—Requirements with guidance for use. The third edition 2015-09-15. Translation By A. Gorbunova, 2015, 46.

Trubitsina, O. P. (2002). Global/regional acid deposition. In: *Ecology of the Northern Territories in Russia. Problems Forecast of the Situation, the Development, Solutions, Proceedings of the International Conference, Arkhangelsk, 1* (pp. 399–403).

Trubitsina, O. P. (2013). Loads of acid deposition in the north of the Russian plain. *Vestnik NArFU, Series of Natural Sciences, 4*, 44–49.

Trubitsina, P. O. (2014). Investment attractiveness of environmentally oriented enterprises. In: *Actual Problems of Modern Business. The Materials of International Correspondence Scientific-Practical Conference*, *Arkhangelsk* (pp. 82–85).

Trubitsina, O. P. (2015). Ecological monitoring of acid deposition in the Arctic region. *Open Ecology Journal, 8*, 21–31.

Trubitsina, O. P., & Shvartsman, Y. G. (2007). Geoecological condition of atmospheric air in the North of the Russian Plain. *Vestnik the Arkhangelsk State Technical University, Series Applied Ecology, 70*, 151–163.

UBA. (2004). *Manual on methodologies and criteria for modelling and mapping critical loads and levels and air pollution effects, risks and trends*. Chapter 5.5. Available at: www.icpmapping.org.

Part III
New Environmentally Oriented Biogeochemical Technologies for Managing Risk of Environmental Pollution in Gas Production Areas

Biogeochemical Engineering and Development of Biogeochemical Technologies

Vladimir N. Bashkin

Abstract Study of fundamental mechanisms of biogeochemical cycles is resulted in the formation at the intersection of fundamental and applied researches a new field of research—biogeochemical engineering, within which is developing the biogeochemical innovative technologies, namely technologies and technological processes based on the modeling and management of ecosystem biogeochemical cycles, including fundamental biogeochemical mechanisms of formation of geo-environmental risks. In this case, the geo-ecological risk refers to the interdependent impact of the oil and gas industry on the environment, as well as the impact of the environment on the functioning of the industry and health of employees. Taking into consideration the extremely diverse environmental conditions in existing and prospective areas of development of the oil and gas industry of Russia (the Yamal Peninsula, Eastern Siberia, and the shelf of Arctic and North-East seas), it is necessary to consider geo-ecological factors of soil, biogeochemical, relief position, sedimentary, geodynamic and geophysical nature. It allows one to solve fundamental and applied tasks of risk management, including system analysis and quantification. These biogeochemical technologies are used for managing geo-environmental risks in the oil and gas sector. Accordingly, new relevant techniques of assessing and managing geo-ecological risks are exampled for some gas-condensate fields in the Polar region.

Keywords Biogeochemistry • Biogeochemical engineering • Biogeochemical technologies • Gas industry impacted polar ecosystems

V.N. Bashkin (✉)
Institute of Physicochemical and Biological Problems of Soil Sciences of Russian Academy of Sciences, Pushchino, Moscow Region 142290, Russian Federation

Institute of Natural Gases and Gas Technologies—Gazprom VNIIGAZ LLC, Razvilka, Moscow Region 142719, Russian Federation
e-mail: bashkin@issp.serpukhov.su

V.N. Bashkin (ed.), *Biogeochemical Technologies for Managing Pollution in Polar Ecosystems*, Environmental Pollution 26, DOI 10.1007/978-3-319-41805-6_13

1 Introduction

Biogeochemistry is an important scientific discipline, and its rapid development is observed in many countries of the world. Priority directions of biogeochemistry development are based on the notion of universality of biogeochemical cycles and their overarching role in the mass exchange of chemical elements between living organisms and the biosphere, including the soil as its most important component. The quantitative parameterization of multi-scale local, regional and global changes due to natural and anthropogenic impacts requires the quantitative understanding of biogeochemical cycles and it seems to be one of the fundamental branches of modern science. In turn, studying the fundamental mechanisms of quantitative parameterization of biogeochemical cycles makes it possible to demonstrate a number of new R&D directions at the intersection of fundamental and applied researches. A new R&D area is the biogeochemical engineering, through the development of innovative environmental technologies. Biogeochemical technologies are the technology and technological processes based on knowledge, understanding and management of biogeochemical cycles. Scope can be related to mining, biofuel production, biogeochemical standards, risk management, etc.

Considering the application area of biogeochemical innovative technologies, we can highlight the following.

2 Biogeochemical Technologies

2.1 Biogeochemical Technologies for Managing Geo-Environmental Risks

Developing biogeochemical technologies for management of geo-environmental risk in the oil and gas sector should include the study of fundamental biogeochemical mechanisms of these risk formation. In this case, the geo-environmental risk refers to the interdependent impact of the oil and gas industry on the environment, as well as the impact of the environment on the functioning of the industry and health of employees. Taking into consideration the extremely diverse environmental conditions in existing and prospective areas of development of the oil and gas industry of Russia (Yamal peninsula, Eastern Siberia, as well as the shelf of Arctic and North-East seas), it is necessary to consider geo-environmental factors of soil, biogeochemical, relief position, sedimentary, geodynamic and geophysical nature. Ultimately, the carrying out these biogeochemical studies will develop fundamental and applied tasks of risk management, including quantification and system analysis of such risks. The technology of analysis of geo-environmental risks when developing gas-condensate deposits in the Polar region can be exampled. This technology of risk analysis is focused on obtaining retrospective forecast data in relation to specific environmental effects and certain groups of recipients or production facilities. As criterion of an assessment of geo-ecological situation, risk indicators help identify, classify and rank natural-technical systems, geosystems, located in the zone of influence of emissions of polluting substances, according to the degree of their exposure to different forms of environmental danger or hazard violations. Such assessments can be presented in the form of threshold values for the most likely environmental or socioeconomic damage, or as the probability of their occurrence. The technology of assessing geo-environmental risk is based on the calculation of critical loads of acidifying and eutrophic nitrogen and sulfur compounds that are emitted resulting from the operations of oil and gas companies, as well as the assessment of their exceedances and the extent of uncertainty of input parameters. Technological methods of calculation of critical loads (CL) are based on quantitative parameterization of the main streams of migration of elements in ecosystems, which are specific for different bio-climatic and landscape conditions (Priputina et al., Biogeochemical cycling and SMB model to assess critical loads of nitrogen and acidity for terrestrial ecosystems in the Russian Arctic).

The calculated probability of CL exceeding (geo-ecological risks) defines the geo-ecological situation in the impacted areas. Then we can calculate the ranks of acceptable risk for various ecosystems in the impacted zones and identify methods of managing these risks (Bashkin and Priputina 2010; Bashkin et al. 2012; Bashkin 2014a, b, 2015, as well as Bashkin and Priputina, Possible indicators for assessing geo-environmental risk in polar ecosystems of Yamal peninsula in relation to pollutant emission during gas production and Priputina et al., Biogeochemical cycling and SMB model to assess critical loads of nitrogen and acidity for terrestrial ecosystems in the Russian Arctic).

2.2 Biogeochemical Technologies for Controlling Cycles of Nitrogen and Carbon in Impacted Ecosystems and Managing Geo-Ecological Situations

Monitoring and modeling of dynamics of nitrogen and carbon as the main emitted pollutants in the gas industry impacted zones in Polar region allows for the analysis of parameters of biogeochemical cycles of these biophilic elements in the relevant ecosystems and accordingly for developing technologies of risk management. In turn, it will allow in these areas to regulate the vegetation cover and to maintain its protective properties for limiting process of soil thawing in the areas of hydrocarbon productions (natural gas, gas condensate and oil production). These approaches base the biogeochemical technology for retrospective and predictive assessing geo-ecological situation in the areas of hydrocarbon deposit developing in the Far North. The necessity of analysis of the dynamics of geo-ecological situation is due to extensive and prolonged time exposure of the gas and oil complex to the natural environment and, simultaneously, counter the influence of anthropogenic changes of natural conditions on the safe operation and security of businesses and infrastructure facilities in the medium and long term. Such information allows us to identify polluted natural ecosystems exposed to increased environmental hazards. Furthermore this technology is valid for developing and justifying measures to minimize and prevent the regional negative environmental changes. Consideration of this aspect in the framework of Environment Impact Assessment (EIA) procedure will increase the effectiveness of the system of environmental management, both at the level of individual businesses and at the corporate level. In relation to objects of the oil and gas sector additional rationale for assessment of geo-ecological situation is the fact that geo-ecological conditions in the areas of development of deposits determine successful exploiting technological equipment and infrastructure. Finally this technology was normed as the standard of LLC "Gazprom Dobycha Yamburg".

2.3 Reclamation of Polluted and Disturbed Soils and Grounds

Another direction for the use of biogeochemical technologies is associated with different rehabilitation of disturbed and contaminated soils in impacted zones of oil and gas industry, as well road construction, excessive grazing, etc.

3 Conclusive Remarks

Therefore, in the subsequent articles in this Volume will be given examples of development and use of various biogeochemical technologies.

References

Bashkin, V. N. (2014a). *Biogeochemistry of polar ecosystems in gas industry impacted zones*. Moscow: Gazprom VNIIGAZ. 301pp.
Bashkin, V. N. (2014b). Environmental risks: Definitions and calculations. *Problems of Risk Analysis, 11*(5), 4–6.
Bashkin, V. N. (2015). Use of biogeochemical technologies in risk assessment. *Problems of Risk Analysis, 12*(5), 4–6.
Bashkin, V. N., & Priputina, I. V. (2010). *Environmental risk management at emission of pollutants*. Moscow: Gazprom VNIIGAZ. 189pp.
Bashkin, V. N., Arno, A. B., Arabsky, A. K., Barsukov, P. A., Priputina, I. V., & Galiulin, R. V. (2012). *Retrospective and forecast of geoecological situation on the gas condensate fields of the far north*. Moscow: Gazprom VNIIGAZ. 280pp.

Biogeochemical Standards for Environmental Managing Polar Ecosystems

Vladimir N. Bashkin and Irina V. Priputina

Abstract The article describes the methodological issues of using critical loads to assess environmental risks in the areas of gas production in the Arctic region. The threats and risks for terrestrial ecosystems owing to air pollution by nitrogen compounds as the result of technogenic NO_x emission have been analyzed. The ecological situations in northern ecosystems in connection with anthropogenic NO_x emission were ranged on the risk criteria.

Keywords Environmental risk • Biogeochemical standards • Gas industry impacted ecosystems

1 Introduction

At present sustainable environmental management of polar ecoregions of Russia is of the great importance due to increasing hydrocarbon production (HC) in these areas (Markelov et al. 2013). In turn, it will depend in particular on the sustainability of biogeochemical cycles in the gas industry impacted ecosystems (Bashkin 2014). Accordingly in the regions of gas production the given sustainability can be performed on the basis of reasonable criteria and with the use of modern scientific and technical methods of international level that will improve the effectiveness of environmental management in the impacted areas. An important point is that the study of the response of the natural environment on the same type of anthropogenic action makes it possible to apply the method of analogies to other HC fields of the Far North. Among the representative environmentally sound ways of environmental

V.N. Bashkin (✉)
Institute of Physicochemical and Biological Problems of Soil Science of Russian Academy of Sciences, Pushchino, Moscow Region 142290, Russian Federation

Institute of Natural Gases and Gas Technologies—Gazprom VNIIGAZ LLC, Razvilka, Moscow Region 142719, Russian Federation
e-mail: bashkin@issp.serpukhov.su

I.V. Priputina
Institute of Physicochemical and Biological Problems of Soil Science of Russian Academy of Sciences, Pushchino, Moscow Region 142290, Russian Federation

V.N. Bashkin (ed.), *Biogeochemical Technologies for Managing Pollution in Polar Ecosystems*, Environmental Pollution 26, DOI 10.1007/978-3-319-41805-6_14

management are biogeochemical standards, appropriate technology and biogeochemical techniques to minimize geoecological risks for different scenarios of emission impacts (retrospective, current, forecast).

2 Biogeochemical Standards

To prevent reversible and/or irreversible damage to natural biogeochemical cycling of land and water ecosystems it is necessary to limit the anthropogenic loads by the natural deviations of different links of biogeochemical food chains that, as a rule, shall be accompanied by a substantial reduction of these loads (Bashkin et al. 1993). To determine the required impact reduction there are different techniques in toxicology and environmental chemistry related to setting different standards, like maximum permissible concentrations, MPC, or approximate permissible content of pollutants in different media. These techniques are mainly based on simulation with experimental animals and the results are often very far from the real environment, which makes the application of such standards is controversial from an environmental and economic point of view.

The concept of critical load (CL) according to the definition (Nilsson and Grennfelt 1988), corresponds to the maximum income level of pollutants into the ecosystem, which is not accompanied by irreversible changes in the functioning of the biota, ecosystem structure and productivity over a long period of time—up to 100 years or more. Thus, the evaluation values of CLs implies the threshold for contaminants in the ecosystem, beyond which there are possible negative effects on living organisms and the ecosystem as a whole, whereas below this level violations and adverse effects are not observed. Unlike traditional for Russia and most other countries "environmental" indicators, normalizing the concentration of pollutants in separate environments, the value of CLs is an ecosystem indicator. The main differences between these standards are reflected in Table 1.

Estimates of the quantities of CLs, as biogeochemical standards, focused on establishing quantitative relationships between the impacts of specific contaminants and resulting environmental reactions, which is especially important from the point of view of ecological and economic substantiation of administrative decisions. Quantitative indicators on the acceptable level of anthropogenic pollution impacts on specific ecosystems can be established on the basis of experimental or monitoring studies. These are empirical critical loads. However for the areas with high natural diversity and uncertainity of monitoring database, like Polar region of Russia, the quantitative methods of evaluation values of CLs on the basis of mathematical calculations involving the capabilities of modern GIS-technologies look more reasonable.

Quantitative methods for calculating the values of CLs are based on the use of simple chemical models of the mass balance of the elements (UBA 2004). In the evaluation of critical loads it can be taken into account certain environmental priorities determined through the selection of recipients (conservation of specific natural features) and the establishment of relevant biogeochemical indicators.

Table 1 Basic principles and use of maximum permissible concentrations (MPC) and critical loads (CLs)

Maximum permissible concentrations of contaminants	Critical loads
Normalized the content of pollutants in separate environments (soil, vegetation, groundwater and surface water) without chemical bonds between the components of ecosystems and specific migration flows of pollutants	Characterize a maximum flow of pollutants in ecosystems with consideration of potential resistance against the effects of specific pollutants
Designed primarily to assess the quality of agricultural soils, water fishery, drinking water, typically on the basis of laboratory studies	Take into account biogeochemical linkages between the individual components of existing ecosystems and natural variations of the parameters of the individual environments
Does not take into account the specificity of functional use of territories	Allow to assess the level of anthropogenic load based on the functional use of territories, including from the standpoint of environmental safety of various recipients (human, terrestrial or aquatic biota, soil fauna and microorganisms)
Anthropocentric—as principal recipient of impacts are considered people	Give an idea of the ratio of the existing and allowable exposure, allow you to adjust the intensity of the impacts and focused on the economic feasibility of reducing loads
Characterize the degree of anthropogenic changes in the chemical composition of the media, without taking into account the intensity of previous, existing or allowable impacts	Do not allow to establish quantitative relationships between exposure and its consequences

Currently in the CL calculations of the most widely use are effect-oriented models, which are based (1) on the idea of the relative biogeochemical equilibrium that exists between the different components of the ecosystems under stable external conditions, and (2) on the specific environmental consequences from anthropogenic impacts. This allows us to calculate the allowable income level of pollutants, the corresponding critical concentrations of pollutants in one of these environments, and to fulfill the condition to preserve the quality of those environments, which are defined as ecologically priority for these conditions. Standardization of technogenic load on the basis of such models is carried out for environmental situations where the level of contamination of individual components of the ecosystem below the established critical standards, and from an economic point of view there is more intensive use of the territories, which, however, should not lead to pollution of environmental components above the established standards. For conditions when the existing level of pollution above the established standard indicators, for the assessment of acceptable intensity during further use of the territories and (or) for determining the parameters required to reduce the anthropogenic loads the dynamic model is using (Posch et al. 2007).

In Europe in the area of research on the Convention on long-range transboundary air pollution, LRTAP Convention (Convention on Long-Range Transboundary Air Pollution, http://www.unece.org/env/lrtap/) in respect of acidifying substances and eutrophication actions due to nitrogen oxides emissions, including gas industry emission, special methods of calculation of critical loads have been developed.

3 The Algorithm of Calculation of Critical Loads of Anthropogenic Acidifying and Eutrophic Compounds for Terrestrial Ecosystems

Calculations of CL quantities include the parameterization of the basic elements of migration flows that are specific to different bioclimatic and landscape conditions. Detailed methods of calculation of the CL values are presented on the website of the Working group on CL estimation and mapping of the LRTAP Convention (www.icpmapping.org) and in (Bashkin and Priputina 2010). Let us discuss some principal points used in these calculations. Most frequently to quantify the CL values simple (biogeo)chemical models are using that include equations of two types: (1) the equilibrium equations of a simple mass balance of elements and their compounds in the soil (soil layer); (2) the equations describing the intensity of the main biogeochemical fluxes of elements in ecosystems with consideration of the peculiarities of their formation.

In these models is done by a number of assumptions, namely: (1) Depth of the considered soil layer is conventionally equal to the depth of the root zone, which allows to neglecting the cycle of nutrients. (2) Evapotranspiration occurs on the surface of the soil profile. (3) Seepage of moisture from precipitation is constant throughout the soil profile, and only occurs vertically. (4) Physico-chemical constants are taken uniform over the entire soil profile. (5) Internal threads of the elements (nitrogen fixation, etc.) do not depend on chemical conditions of the soil (such as pH).

Also not included internal ecosystem interactions and processes such as intraspecific competition or the presence of pests, removal of elements from the soil with the increase of the part of the aboveground biomass, which annually returns to the surface with vegetation litter, and others. As these models describe conditions regarding biogeochemical equilibrium state, that they require as input information the long-term averaged values of the incoming flows. Seasonal, inter-annual and other short-term dynamic changes of indicators in these models, generally, are not reported. In Europe, where in most countries there is a fairly detailed network monitoring field observations, the calculation of the CLs values are normally measured averages. For example, in the Netherlands, the detailed network of soil-geochemical agricultural and forestland is 500 × 500 m, and for each point in the nodes of this grid with varying periodicity values of pH, granulometric composition of soil, organic matter content, etc. are measured. However, when CLs calculations for relatively large regions, regions with a low degree of knowledge or natural complex structure of organization, problems arise with a high degree of uncertainty and differentiation of input parameters. In this case, in our opinion, the most correct assessment can be obtained through the use of probabilistic methods (e.g. Monte Carlo method), when for different areas the possible ranges of values CLs are calculated with subsequent analysis of indicators corresponding to different levels of values (usually, 25 %, 50 %, 75 %, 95 %). This approach has advantages from the point of view of inclusion of the data obtained to assess the likelihood of environmental risks and subsequent management decisions. This approach is realized by us on the basis of a number of objects of JSC "Gazprom" (Priputina and Bashkin 2008; Bashkin and Priputina 2011; Bashkin et al. 2009, 2012). Thus, on the basis of ecosystem biogeochemical models biogeochemical standards can be calculated, which, in turn, are used for calculations of geoecological risks.

4 Algorithm for Assessing Geoecological Risks with the Use of Critical Loads

Under the umbrella of the LRTAP Convention ecological risk assessment for terrestrial and freshwater ecosystems due to air pollution is using to determine the probability of environmental violations, the calculation of the so-called "critical load exceedances" (Critical Load Exceedance, Ex(CL)). The CL exceedances are estimated as the difference between actual (or projected) income of pollutants into ecosystems from atmospheric deposition and corresponding CL values (Hall et al. 2001). Under this approach, the positive values of the exceedances CL (Ex(CL) > 0) indicate that the permissible exposure levels of pollutants for specific ecosystems (areas) have been exceeded and environmental violations are possible in the structure and function of natural ecosystems, due to the influence of the considered pollutant. Since CL calculations and deposition of pollutants under the LRTAP Convention are implemented with the use of deterministic data (based on averages), the results are not "classical" indicators of risk.

In our opinion, from the methodological point of view, a more accurate assessment of environmental risks can be obtained by combining this approach with probabilistic methods when the risk characterization includes the calculation of the probability of exceedance of CLs (or the probability of exceedance of acceptable levels of exposure) that can be expressed by the following equation:

$$Risk(X) = P(Ex(CL) > 0) = P([X]dep - CL(X) > 0), \tag{1}$$

where: *Risk(X)*—environmental risks to ecosystems associated with exposure to a specific pollutant *(X)*; *CL(X)*—allowable income level of this pollutant in the ecosystem (critical loads); *[X]dep*—existing or projected level of income of the pollutant in the ecosystem from atmospheric deposition; *Ex(CL)*—exceeding the permissible level of income *(CL)*; *P(Ex(CL))* is the probability of exceedance of the allowable level *(CL)*.

Technically, the calculation of the probability of exceedance of CL may be performed, for example, using the Monte Carlo method (Sobol 1985). In accordance with the proposed formula, exceeding CL reflect the ratio between the amount of exposure of the recipient (within the zone of influence of existing or planned production facility) and the level of exposure that is safe for the recipient. Since CLs are not integral indicator of ecosystem sustainability, these are focused on the rationale for allowable impacts for specific pollutants and specific effects. This allows the use of this indicator to quantify environmental risks of partial the same way as it is done in the calculations of multifactor anthropogenic risks or risks to human health (Onishchenko et al. 2002; Kolesnikov 2008). It should be recognized that in this form of the proposed formula does not include quantitative parameters of environmental damage associated with economic activity, although fully consistent with the definition of "environmental risk" from the Russian Federal law No. 7-2002 "On environmental protection". Damage assessment for the environment in this case is based on the characteristics of the changes that are possible in specific ecosystems in excess of the permissible levels of inflow of pollutants that is taken into account in the CL calculations.

If between the level of considered impacts and related environmental changes is possible on the basis of experimental studies to identify suitable quantitative dependencies, the proposed formula can include required factors (or values), allowing to consider the amount of environmental damage at a given probability of occurrence of adverse events. In addition, if such assessments are performed on a regional scale for different types of ecosystems within the entire zone of influence (from the maximum level of income pollutants to a minimum), we obtained the spatial distribution of zones with different levels of probability of exceedance CLs as the quantitative characteristic of territorial risk.

5 Management of Geo-Environmental Risks

Integrated anthropogenic impact on the ecosystems of the Far North, inevitably produced in the process of production of hydrocarbons, requires regular and objective assessment of geoecological situation, allowing an acceptable level of likelihood and confidence statements to track the dynamics occurring environmental changes to minimize the negative effects of the ongoing economic activity. At the legislative level, these issues are regulated in Russia by some Federal laws, including, No. 7 "On environmental protection" of 10.01.2002, No. 174 "On ecological expertise" of 23.11.1995, No. 96 "About protection of atmospheric air" of 4.05.1999, etc. The normative criteria for analysis and evaluation of geoecological situation in connection with economic activities at present are the environmental standards for emissions and discharges (MPE) of pollutants into environment. They adopt the maximum permissible concentration (MPC) of pollutants in environmental compartments (air, soil, water bodies) authorized by the approximate safe impact levels (ASIL) of pollutants for natural environments, etc. (Gritsenko et al. 2009).

At the same time, in modern society the problem of anthropogenic impact on the environment, along with the security problems of human life, safety or used new technology and product quality, are recognized risk areas requiring the use of appropriate criteria and methodologies for analyzing the causal relationships between various risk factors and their ecological and socio-economic consequences (Night 2006). The advantage of the methodology of risk for the decision of tasks of ensuring the effectiveness of economic activity is due to the relative flexibility of the approaches and tools of managerial decision-making. Being an integral part of effective management at the corporate level, the risk management process helps to identify what aspects of safety, quality and environmental management is important to achieve corporate goals.

Ecological policy of JSC "Gazprom" in the field of environmental protection defines the major priorities of the company, the preservation of the natural environment in the areas of placing of objects of the gas industry, environmental management, environmental safety of construction and operation of facilities for mining, processing, transportation and storage of gas, and the participation of subsidiaries of JSC "Gazprom" for ensuring ecological safety of regions of placing of objects of JSC "Gazprom". In this regard, the heightened importance for the successful implementation of the corporate environmental policy are the issues of methodology and scientific basis of representative criteria for the assessment of the environmental risks, which correspond with various technological processes in the gas industry and are crucial for the formation of geoecological situation in the areas of gas production and gas transportation in the present and in future planning.

Of particular relevance to the issues of environmental safety on the basis of comprehensive analysis and management of environmental risks are becoming in the areas of resources development in the Far North, where the ecological consequences of anthropogenic impacts on environmental components are particularly bright and a longer-term perspective. In areas with extreme conditions (permafrost, etc.), significant disturbances of natural conditions made by objects of gas production, often cannot be neutralized by natural processes of self-regulation in the relevant norm-defined time. While geo-environmental changes take place, both during the emergency and during normal situations. For example, the zone of partial destruction of the plant cover at the expense of a single transport journey in the Far North on the trails and surrounding the mine site territories is a significant proportion of space exploration. About half of these territories are sites after fires. In addition to direct risks to natural ecosystems in the North and traditional nature use of the indigenous population of these regions, the danger of anthropogenic disturbances of the ecological balance between the different components of the environment are associated with the inevitable increase risk for industrial facilities and infrastructure, primarily due to the worsening of their condition and the conditions of use result in changes in physico-chemical and thermal properties of the soil. Thus, sustainable development of the domestic gas industry in general and its separate structures, including a subsidiary of JSC "Gazprom", is not possible without taking into account dynamics of development of geoecological situation in the areas of development of deposits of the far North and optimal minimization of emerging environmental risks based on science-based assessment procedures and risk management.

All this fully applies to the LLC "Gazprom Dobycha Yamburg" and its production facilities, the operation of which takes place in the harsh climate of the North of Western Siberia. Gained so far in LLC "Gazprom Dobycha Yamburg" long-term and successful experience of environmental activities allows the use of existing information material data and traditional ecological monitoring to substantiate representative environmental criteria, the development and testing of methodological approaches for forecasting and retrospective assessment of geo-ecological situation and ecological risks for the environment in relation to atmospheric emission of pollutants in gas production in the far North.

6 Analysis of Approaches to the Assessment of Geoecological Situation in the Areas of Impact of the Gas Industry on the Basis of Criteria of the Methodology of Risk

Research in the field of environmental protection has traditionally focused on the identification and analysis of environmental consequences of already occurring (or have occurred) anthropogenic impacts on public health, the state of biota or the quality of natural environments, that is a statement of fact past environmental violations. Representative criteria for these retrospective assessments are widely used in our country and abroad so-called environmental regulations of pollutants: maximum permissible concentration (MPC), approximate permissible concentrations (APC), etc. Their counterparts, which can also be used in such assessments of geo-ecological situations are such indicators as "No Observed Effect Concentration, NOEC" or "Lowest Concentration, LC10, LC50", which are calculated on the basis of statistical data of experimental studies at different levels of the probability of occurrence of adverse effects (typically to 10 % or 50 % levels) (Onishchenko et al. 2002). Comparative analysis of pollution levels of ecosystem components and respective MPC (NOEC, LC) provides an opportunity to identify the presence of past environmental changes in the components of the environment, but makes it difficult to assess their risk for different groups of recipients and analysis of the acceptability of such risks at the regional level. In addition, this approach does not allow us to determine the parameters necessary to mitigate emissions of pollutants associated with significant financial costs and, therefore, requires special ecological-economic justification (Samsonov et al. 2007).

The criteria that constitute forwardlooking regulatory indicators include indicators such as MPE and ASIL, used to assess the impact of industrial emissions on air quality. Maximum permissible emissions of pollutants into the atmosphere set for each source of air pollution, provided that emissions of pollutants from this source and from the set of sources will not create a near surface concentration of contaminants above the relevant limit values for the population, flora and fauna. Thus, the standardized direct effects of anthropogenic compounds on human and biotic components of the environment associated with inhalation exposure. On the basis of such regulations, including the established sanitary protection zone (SPZ) production, also taking into account the hazard class of the contaminants present in the emission emissions. For companies of natural gas production the size of the SPZ, as a rule, is an area with a radius of 1000 m from the emission sources, and with increased content in the raw material of the sulfide—up to 5000–8000 m (Gritsenko et al. 2009).

However, environmental standards, such MPE or ASIL do not take into account multiple secondary (or indirect) environmental effects of the emission impacts that occur in natural ecosystems as a result of anthropogenic compounds from atmospheric deposition to the surface land cover and their subsequent migration through trophic chains. With regard to long-term impacts of emissions characteristic of the normal operation of production facilities, secondary effects due to the cumulative deposition of pollutants in different environments (soils, crop production, soil and ground and surface waters) have a greater environmental risk. At the present stage of interaction between society and environment are becoming increasingly relevant identification and minimization of the complex of such negative effects and potentially dangerous environmental situations at the stage of design solutions taking into account ecological and economic feasibility of economic activity. Increasingly to solve such problems the methodology of risk is involved (Risk Analysis 1992).

In Gazprom company practice, risk methodology is widely used in the implementation of domestic and international projects, including in the area of environmental protection, starting from the 90s of the last century (Bashkin et al. 2006; Samsonov et al. 2007; Rusakova et al. 2009). On the one hand, this is due to the need to comply with the legislative framework of a domestic nature that postulates the presumption of ecological danger of any kind of economic activity and requiring business entities to prevent possible adverse impacts on the environment and the associated environmental risks, manifested in the occurrence of adverse geo-ecological situations. On the other hand, current trends in the development of major industrial corporations, including Gazprom JVC and its subsidiaries, in particular, LLC “Gazprom Dobycha Yamburg” focusing the business on the responsible use of natural resources, preservation of favorable environment and creating a positive “environmental image”, also dictate the need to prevent and economically feasible reduction of geoecological risks associated with the construction and operation of industrial sites.

As a measure of risk situations in which there are potential negative factors impact on people, society and nature, the concept of risk combines the probability of an unfavorable event and the volume of its existence, expressed through the damage, loss, damages, etc.. In accordance with the general theory of risk, geo-ecological disturbance as a result of anthropogenic impacts on the environment occur, when permissible levels of technogenic load on the recipients (ecosystems, individual organisms or natural environment) are exceeded (Risk Analysis 1992; Protsenko 2006). In this case, the risk indicators characterize the likelihood of adverse situations and related damages. The most universal criteria for assessing varying geoecological situation is the monetary value of the costs for the prevention or correction of adverse changes in the environment and human health or costs (financial compensation) for any environmental violations (Lesnykh 1999; Bykov 2007).

However, unlike industrial or infrastructure facilities, ecological systems have differentiated potential for sustainability in relation to anthropogenic pressures, similar in nature, impact and intensity. In addition, most changes in the environment arises simultaneously with the impact, and after some time, which makes it difficult to establish unambiguous causal links between environmental risk factor and its (often multiple) manifestations. Equally important is the dependence of the current state of natural systems and biota from multifactorial influences, including retrospective effects without documentary evidence. Into force of such a complex nature of the interactions of modern production systems with the environment, the practical solution of problems of assessment and management of geo-environmental risks is carried out, typically using techniques and methods of system analysis, including multivariate decomposition of the complex interactions at individual components, described using relatively simple models, and subsequent synthesis of results for your search of strategic solutions (Samsonov et al. 2007). The risks themselves are distinguished depending on the sources of impact of hazards/damages, extent and levels of manifestation of adverse effects of typicality or frequency of existence, etc.

The chain of causes leading to industrial accidents and other risks and associated damages (economic, social or environmental), identified and analyzed, usually based on a deterministic approach that does not contradict the probabilistic nature of risk and the need to perform probabilistic assessments in the calculation of risk indicators (Gritsenko et al. 2009). Criteria of security evaluation of geoecological situation can be represented in the form of threshold values for the most probable damage or the probability of its occurrence. Thus the estimation of environmental damage is the most difficult task, because the results of technogenic impacts on the natural environment currently to a greater extent are characterized by qualitative than quantitative indicators. Even if some of the scientific assumptions about the consequences of anthropogenic impacts on biota and ecosystems have a decisive influence, the results of the predictions using the models show mostly what might happen, whereas this probability is not known. Despite the fact that the costs of reducing emissions should be made in the moment or in the near future and the cost of decommissioning environmental impacts—in the distant. But as the person responsible for making decisions in the sphere of production and environmental safety, can not ignore the risk of anthropogenic changes of the biosphere and its components, they must take into account not only accurate scientific facts, but objectively existing scientific uncertainties associated with the probabilistic nature of interactions in the "technosphere" and "environment" and the incomplete nature of current scientific knowledge about the world (Peti 2004).

The risk of negative changes in indicators of population health and status of natural components as a result of anthropogenic activities is largely determined by the probabilistic nature of most processes in the environment and the technosphere. In the case of environmental risks associated with, for example, man-made pollution of natural environments, we are faced with the influence of many different factors that determine the response of ecosystems and their biotic components on emissions. But due to deficiency of our knowledge about the nature of influence of these factors, their dynamics and natural variability of most natural indicators, unambiguous prediction of the occurrence of the alleged adverse outcome. Precisely because of this, the environmental risk assessment is particularly necessary when it is impossible to give a definite answer about possible ecological consequences of anthropogenic impacts on the environment due to a number of probabilistic causes (Bashkin 2006, 2014; Bashkin and Priputina 2011). These reasons may be related to the following uncertainties: (1) the uncertainty of available information on the nature of the impacts; (2) the uncertainty of the algorithms used for the estimation of anthropogenic impacts in the absence of knowledge about the processes and their parameters, or insufficient knowledge about them, or proposed to simplify these processes; (3) uncertainty in establishing the zone of impact of pollutants.

7 Methods of Quantitative Estimating Geoecological Risks

Common core provisions of the methodology of risk analysis depending on the scope of its practical application are implemented through specific methods (algorithms) of quantitative risk assessment on the basis of these or other representative criteria that are important to this field. In relation to the environmental risks of anthropogenic impacts on the environment standard analysis algorithm includes interrelated procedures identifying environmental hazards from exposure factor, estimates of exposure levels, dose-effective assessment of contaminants in relation to the main groups of recipients, quantitative risk profile and stage of risk management (Table 2).

The risk management strategy seeks to minimise anthropogenic impacts on natural systems taking into account the potential of their stability with respect to specific pollutants, as well as to optimize technical solutions and the development of pro-

Table 2 Stages of ecological risk analysis (Bashkin 2006)

Hazard identification (Identifying factors and sources of environmental risks, monitoring of the ecological state of natural objects)
↓
Exposure assessment (Determination of fluxes of pollutants, the boundaries of their distribution and potential groups of recipients, the assessment of exposure concentrations, etc.)
↓
Dose-response (Parameterization reversible and irreversible impacts, establishment of relationship between "dose-effect", the definition of potential ecosystem resilience, etc.)
↓
Risk characterization (Quantitative calculations of risk indicators for different groups of effects, receptors and exposure scenarios)
↓
Risk management (Development and analysis of scenarios of reducing risk indicators, economic valuation of the costs of risk reduction)

grams to restore natural systems (Bashkin 2006; Samsonov et al. 2007). This strategy is possible on the basis of system analysis and full consideration of the complex factors that determine specific environmental risks and have regional specificity. In addition, the specificity of the analysis of geoecological risks associated with the need to establish quantitative causal relationships between exposure and its implications for complex multi-component, multi-media and multi-view objects, which are natural-territorial complexes of different hierarchical levels.

Within the rationalistic concepts used in exact and natural sciences, to identify risks statistical methods are applied that allow to measure the probability of adverse events and to assess the nature and extent of the damage as a result of exposure to a risk factor (Methodical.. 1999). For situations, the probability of which is high and which accumulated sufficient statistics, the magnitude of the risk can be calculated as the product of the probability of events and the magnitude of the damage, expressed as the mathematical expectation of damage in monetary terms (Kolesnikov 2007). For adverse events, characterized by a low statistics, a number of authors propose to characterize the risk of two independent components: the probability and damage (Protsenko 2006). This approach to the "probability of risk" corresponds to the definition of "environmental risk", given the Federal Law "About environmental protection".

"Risks with small statistics" include geo-environmental risks associated with exploration and exploitation of gas fields, for example, in remote regions of the North, because at the present time there are practically no experimental and monitoring data on quality and quantity of responses of ecosystems to these impacts. Nevertheless, the environmental damage caused by these impacts can be described qualitatively or quantitatively using indicators such as the possible reduction in ecosystem productivity as a result of their breach of, or through the deterioration of the quality of the biomass, allowing you to jump to economic evaluations (cost terms) of such effects.

As an example, the existing methods of valuation of environmental damages can cause "Methodology for evaluating environmental risks of biological components of the ecosystem (including humans) and ecological and economic damage to the natural environment in areas of storage and destruction of chemical weapons" developed in the research centre "Ecological safety" by team of authors headed by Murzin et al. (2006). In this method, the authors propose to determine the risk for "basic community" (R_n) as "damage to natural ecosystems from contained in its environment of toxic substances". This damage is proposed to evaluate relatively ecosystems that are in optimal functioning conditions at the same in its climatic and biogeochemical conditions, but pristine area, using the following equation:

$$R_n\left(x_n,t\right)=H_n\left(C_1,..,C_A,t\right)/B_{n1} \tag{2}$$

where, $H_n\ (C_1,\ ..,\ C_A,\ t)$ is a natural prejudice to the elementary community as a result of the action of pollutants, calculated by the difference of production in polluted and unpolluted ecosystems (kg/m^2); B_{n1} is the maximum achievable amount of matter and energy for primary producers in the level of impact on the community x_n, quantity of pollutant (kg/m^2); t is the exposure time (exposure).

Apart from the fact, that in the proposed approach, the "lost" probability component of risk, the use of this method requires the availability of data on the productivity of ecosystems for different levels of contamination of certain pollutants and background characteristics of the same ecosystem types. This limits the application of the technique in the absence of such factual data for many regions of the Russian Federation.

Another principle of risk assessment is used to analyze risks to public health due to unfavorable factors of the environment against pollutants—noncancerogens (Avaliani et al. 1996; Onishchenko et al. 2002). In accordance with the general views of geochemical ecology, ecotoxicology and environmental epidemiology (Kowalski 1974; Revich et al. 2004), adverse changes and abnormalities in the structure and functioning of living organisms and natural systems occur in case of exceeding certain thresholds upon the toxicants identified as critical (reference) acting dose or critical loads. Under this approach, if an effect (exhibiting the recipient) exceeds the permissible exposure level (critical load or reference dose), then the situation is characterized as "risk", and the frequency of exceedances of the allowable impacts—as an indicator (factor) of risk. The level of exposure is determined by the concentration of pollutants in the border (acting) environments. As a threshold concentration in the risk calculations can be used MPC and APC or the already mentioned standards NOEC, LC10, LC50, and others.

$$HQ = AD / RfD \tag{3}$$

where: HQ is the hazard ratio; AD—average acting dose, RfD—reference (safe) dose or critical load of a pollutant.

Thus, if the calculated value $HQ > 1$, then the given environmental situation at the qualitative level can be characterized as "risk". It should be noted that a similar approach is used in a number of technical problems to assess the risk of failures and accidents and is defined as the principle of "on/off" (Kolesnikov 2008). Exceeding the permissible level of exposure can be calculated using deterministic or probabilistic methods of assessment. In the case of using probabilistic methods (e.g., based on the procedures of Monte Carlo) indicator of risk is the likelihood of adverse ecological effects to selected groups of recipients.

Due to adaptation-specific differences and depending on the ambient conditions, the reference dose and the critical loads of the same pollutants for different groups of recipients can be significantly differentiated. Thus, assessing the environmental risks associated with pollution of the environment, and minimization is possible on the basis of ecologically based intensity normalization of economic activity, taking into account specifics of such recipients and the natural conditions of specific regions. In the basis of such valuation in studies (UBA 1996, 2004) was used the index of "critical load", which is the ecosystem criterion for characterizing the stability of natural-territorial complexes to the effects of (receipt) of pollutants of different directions of action (acidifying, eutrophic, ecotoxic, etc.).

Naturally, in real conditions there is a combined impact of many different factors that determine the response of the biota and ecosystems to the receipt of anthropogenic compounds. Due to the lack of our knowledge about the nature of influence of these factors, their dynamics and variability of most natural indicators, unambiguous prediction of the occurrence of the alleged adverse outcome is difficult. All this, together with the existing uncertainties in ecological-economic models to evaluate the damage from pollution complicates the processes of regulation of anthropogenic emissions of pollutants in various industries and transport. Thus, the estimation of environmental damage is the most difficult task, because the results of technogenic impact on the natural environment currently to a greater extent are characterized by qualitative than quantitative indicators.

8 Identification of Environmental Hazards for the Zone of Influence of Emissions of the Production Facilities of LLC "Gazprom Dobycha Yamburg"

In accordance with the general principles of the methodology of risk, this section of the paper presents the results of the first phase of the evaluation of geoecological risks to gas industry impacted ecosystems, i.e. impact of emissions from the facilities of LLC "Gazprom Dobycha Yamburg"—stage "hazard identification".

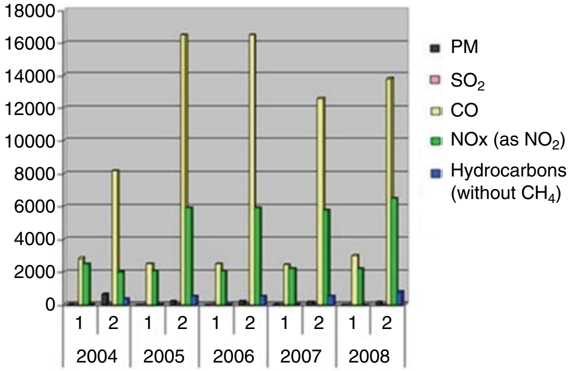
Pollution of the atmosphere with harmful emissions of gas industry is due to the complex composition of the raw materials and technological processes, including emissions from the combustion of fuel using equipment. Differentiated estimation of emissions of harmful substances into the atmosphere on the objects of production, transportation, storage, processing and redistribution of gas shows that the main impact on the environment provide the transmission system facilities, the contribution of gas production in total emissions is about 25 % (Gritsenko et al. 2009). Specific emissions of pollutants depend on the capacity of process plants and process facilities (e.g., buster power).

In accordance with the classification of emission sources, they are divided by:

1. look—on point/lineal (including dot overlay concentration fields);
2. type—internal/external;
3. time—periodic (due to the technological processes or emergency)/continuous (for basic industrial areas);
4. degree of mobility—stationary/movable;
5. character—on the organized/disorganized.

The criteria of evaluation of geoecological situation in the areas of impacts of production facilities gas industry are the ratio of maximum permissible emissions and real volume of emissions. Maximum permissible emissions, MPE, of pollutants into the atmosphere set for each source of air pollution, provided that emissions of pollutants from this source and from the set of sources will not create a near surface concentration of contaminants above the relevant limit values for the population, flora and fauna. Thus, the excess of the MPE can be regarded as evidence of adverse ecological situation regarding inhalation effects on humans, and possibly biotic components of natural ecosystems within the zone of influence of emissions.

Fig. 1 Dynamics of the total atmospheric emissions of pollutants (t yr^{-1}) of production facilities of LLC "Gazprom Dobycha Yamburg" for 2004–2008 (*1*—fuel combustion, *2*—technological processes)



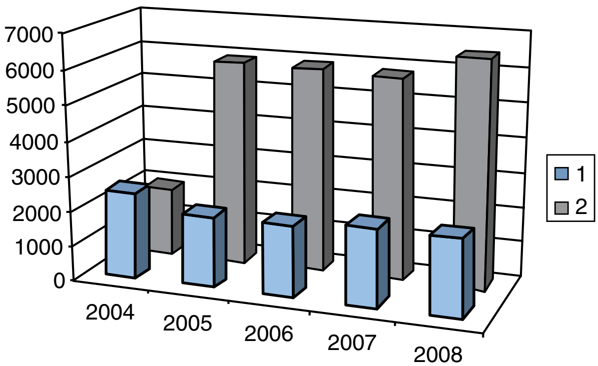


Fig. 2 Evolution of the total atmospheric emissions of nitrogen oxides (tons/year) of production facilities of LLC "Gazprom dobycha Yamburg" for 2004–2008 (*1*—fuel combustion, *2*—technological processes)

8.1 A Retrospective Analysis of the Structure and Dynamics of Emissions of Atmospheric Pollutants from the Facilities of LLC "Gazprom dobycha Yamburg"

According to the environmental services, LLC "Gazprom dobycha Yamburg" data reporting form "2TP-air", the emissions of pollutants production facilities of LLC "Gazprom Dobycha Yamburg" connected (1) with the technology and related processes and (2) the combustion of fuel to generate electricity and heat. The total number of sources of air pollution is about 2000, including about 1700—organized. Not taking into account methane emissions among atmospheric pollutants, the main emissions are carbon monoxide and nitrogen oxides, and hydrocarbons (excluding methane), particulate matter and sulphur dioxide. The ratio of pollutants in the emissions of two groups of different sources is shown in Fig. 1.

Not considering the emissions of methane, the main volumes of atmospheric emissions of pollutants are oxides of carbon and nitrogen. Emissions of solid particulates, sulphur dioxide and hydrocarbons are characterized by a low contribution to the total emission of pollutants.

For most process plants operating in the system of JSC "Gazprom", the main pollutants of the first hazard category, power output, and volume of the annual gross emissions are oxides of nitrogen (Gritsenko et al. 2009). Retrospective dynamics of nitrogen oxides emissions from production facilities of LLC "Gazprom Dobycha Yamburg" for the period 2004–2008 in terms of NO_2 is presented in Fig. 2. As can be seen, the total level of emissions of nitrogen oxides from the combustion of fuel to generate electricity and thermal energy in the period under review remained virtually unchanged, averaging about 2000 tons/year. Emissions of nitrogen oxides associated with technological and related processes, since 2005, were on average three times higher than the combustion of fuel for own needs. Thus, the priority pollutants for the zone of influence of the production facilities of LLC "Gazprom dobycha Yamburg" should be regarded as oxides of nitrogen.

8.2 Analysis of the Conditions of Exposure and Routes of Exposure to Pollutants

Anthropogenic air pollution can cause direct and indirect exposure of recipients. In the first case of inhalation or contact-surface effects of pollutants on living organisms as a result of excessive concentrations of toxicants occurs. The second impact, as a rule, is more complex and involves redistribution of contaminants in environmental compartments after their deposition on the underlying surface with subsequent migration along the trophic chains. Thus, there is formation of several exposure routes.

The general atmospheric circulation of air masses in the Northern part of Western Siberia determines the direction and intensity of migration of pollutants from emission sources to the deposition area of products of their transformation in terrestrial and freshwater ecosystems. According to available data, direction and speed of atmospheric flows in the area are differentiated by the seasons. Autumn-winter-spring period is characterized by West (latitudinal) direction of movement of air masses, alternating in the summer in the South-South-West (close to meridional). The most intensive transfer of moisture and pollutants occurs in the atmosphere in spring. This specificity determines the square of the dispersion and deposition of anthropogenic compounds in components of the environment in the impact zone of objects of JSC "Gazprom Dobycha Yamburg".

Considering the emission of pollutants is relatively uniform throughout the year, we can assume that the spatial pattern of the zone of exposure consists of two components. The most intense total impact occurs in a westerly direction from the emission sources. However, most of the pollutants received by the environment in autumn-winter-spring period, is accumulated in the snow cover, with "shielding" effect. With the spring snowmelt runoff accumulated anthropogenic compounds can be redistributed between geochemically related ecosystems, including, can come in numerous water bodies, forming in them the "peak" concentrations of pollutants. In the summer, which is characterized by a predominantly southern direction of transport of pollutants, there is a relatively even flow of anthropogenic compounds directly on the underlying surface, which can lead to the formation of permanent soil increased "background" pollutants. Depending on the nature and levels of esponiage, environmental effects of emissions of LLC "Gazprom Dobycha Yamburg" on natural ecosystems and different groups of recipients can be differentiated.

Considering these factors in assessments of geoecological risks should accounting for the following routes of exposure:

- Emission sources → redistribution and transformation of pollutants in the air → formation of stray fields of pollutants with different levels of concentrations in the atmospheric surface layer.
- Emission sources → redistribution and transformation of pollutants in the air → deposition of pollutants on the underlying surface → depositing in the upper layer of soil.
- Emission sources → redistribution and transformation of pollutants in the air → deposition of pollutants on the underlying surface → removal of pollutants from the upper layer of soils with soil and groundwater runoff to aquatic ecosystems (wetlands and riverine).

8.3 *Impacted Area Features and Potential Recipients*

Regional impact of the atmospheric emissions of pollutants from the facilities of LLC "Gazprom Dobycha Yamburg" affects ecosystems of Western Siberia, belonging to the southern subzone of the tundra, forest tundra and Northern taiga, which are characterized by widespread permafrost (Natural… 1963). According to landscape zoning (Makunina 1985), the study area belongs to the Nadym-Pur-Taz province and is part of the Northern region of Western Siberia, which is predominantly marine and glacial-marine plains, low absolute elevation (less than 100 m above sea level). Severe frosty climate, the shallow horizon of permafrost and the evenness of the terrain are the distinctiveness of the landscape structure of the territory, the distinctive features of which are the polygonal soil cover and patchiness of vegetation that creates a high spatial complexity of the natural environment, complicating the estimation of ecological consequences of anthropogenic impacts. Due to excessive moisture this area in the modern period is characterized by a high degree of waterlogging and water content, which affects the migration and deposition of substances (including, anthropogenic compounds).

The relatively drained areas in the tundra zone are dominated by moss and moss-lichen plant communities with dwarf shrubs and shrubs on gley and permafrost-gley soils. In the subzone of the forest-tundra and Northern taiga in areas with deeper levels of occurrence of permafrost and the best conditions of aeration the main landscape background are sparse larch mainly with lichen or moss-lichen cover, and shrub-shrub communities on gleaye-podzol soils, alluvial-humus or ferro-humic podzols (Soils of the USSR 1979; Makunina 1985). In connection with the harsh climate and relatively short growing season, the increase in terrestrial biomass in ecosystems of background areas is minor, and also occurs slowly dying and decomposition of organic matter. As a consequence, soils are characterized by low content and low reserves of humus (about 2–2.5 %). In the structure of humic acids is dominated by fulvic acids, mainly associated with iron and aluminum, which determines the increased acidity of soil solutions (water pH of 4.6–4.8) (Kosheleva and Tolstukhina 1964). Soils are weakly base saturated and poor in nutrients, and the removal of products of soil weathering is difficult due to the small slope of the surface. As a consequence, natural waters contain elevated concentrations of organic acids and low mineral compounds. All these indicators show reduced stability of these ecosystems to external influences related to the intake of acidifying and eutrophic compounds.

In depressions and areas with a similar level of occurrence of frozen soil strata are widespread paludification processes. Bogs and marshy sparse forests cover a large area. In accordance with the classification of Shumilova (1969), the territory in question is part of Nadym-Pur subregion of solid flat bogs in combination with polygonal fractured and small-bamped swamps of the Ob-Taz region of frozen peat bogs. The distinctive feature of wetland ecosystems is the dependence of dominant plant groups from the microrelief, which, in turn, is associated with the occurrence of permafrost thickness. On the hills, which occupy relatively elevated terrain elements, more oligotrophic species are dominated: mosses (including sphagnum), lichens (mainly of the genera *Cladonia* and *Cetraria*) and dwarf shrubs (ledum, cloudberries, lingonberries). Vegetation of inter-bump depressions—wetland potholes—is represented mainly by sedges (relating to more eutrophic species) and mosses. The peat layer is typically about 1–1.5 m (rarely to 2.5 m). Peat is mainly sedge, sedge-hypnovel and sedge-sphagnum. Because groundwaters draining this area are fresh, peat and peat water is also characterized by low mineralization (<0.5 g l^{-1}) and acidic conditions (pH = 3.5–5.5). Typically, peat waters are characterized by reduction environment and nitrogen-methane or methane composition of dissolved gases, as well as the enrichment of organic acids. According to available estimates (Nazarov 1977), in the Northern taiga landscapes of Western Siberia is mineralized and taken by hydrochemical runoff in the form of carbonic acid, about 10 % of the biological production of the swamps, and most of the organic substances will be preserved in peat deposits, including increasing the area of waterlogging. A high rate of paludification processes leads to the depletion of soil mineral elements of plant nutrition, contributing to the spread of oligotrophic species (up to sphagnum moss).

The fauna of wetland waters of the West Siberian plain is quite poor, due to the relative monotony of the vegetation cover, tension biocenotic relations, sharp fluctuations of feedstocks for the season and other factors (Nazarov 1977). Bog bodies, as a rule, are small distrainee or oligotrophic lakes are poor in plankton, benthos and other organisms. The productivity of lowland and upland swamps of the territory under consideration is given in Table 3. Because swamp water is poor in oxygen (about 3–5 mg l^{-1}), then spread them in freshwater fish is difficult due to respiratory depression in most species.

Table 3 The productivity of the swamps of North-Eastern part of the West Siberian plain (Nazarov 1977)

Swamp type	Depth of the water column, m	Biomass, g m^{-3}			Productivity rate
		Phytoplancton	Zooplancton	Bentos	
Bog	1–2	0.14	1.8	2.7	Low
Lowland	1.5–10	1.04	1.43	9.3	Mean

At the same time, wetland ecosystems are connected with the life of many species of land animals and birds, including having the status of protected species. Of particular note is the role of wetlands as grazing land for reindeer. For the wild tundra reindeers lichen lofty hills wetland ecosystems of rivers Pura and Pelvis are the main winter feeding grounds, and in the summer they migrate North to Gydan Peninsula. In contrast, wild taiga reindeers in the summer graze primarily on arrays of forest swamps, where in spring and autumn the basis of their diet is twig-grass-lichen forage, and summer—only green grass. Because non-swamped forests of Western Siberia are poor in forage, and flood plains in the summer is not available for deer because of the abundance of mosquitoes, dense shrub cover and watering, forest swamps are most important for populations of reindeer pastures, abundant in summer green forage mass and relatively poor midges (Nazarov 1977).

Berry shrubs of lingonberry, cloudberry, etc.—are important forage value for some bird species (capercaillie, black grouse, etc.), and also as raw materials for the local population. In conditions of Western Siberia half of all berries have on wetlands, where their maturation occurs earlier than under forest cover and productivity, as a rule, above.

Thus, as principal recipients in the impact zone of the atmospheric emissions of pollutants by facilities of LLC "Gazprom dobycha Yamburg" it is necessary to consider the following groups of biota:

1. edificatory ground vegetation
2. lichens and mosses
3. herbaceous and sedge species
4. commercial species of barry shrubs
5. wood species edificatory pre-tundra forests
6. aquatic biota (phytoplankton and zooplankton, fish).

9 Analysis of Potential Geo-Environmental Risks Associated with the Impacts of Emissions from the Facilities of LLC "Gazprom Dobycha Yamburg"

Geoecological risks associated with anthropogenic intake of acidifying and eutrophic compounds (NO_x and SO_x) in the environment as a result of air pollution, and their associated ecological effects are determined by many factors, including,

Table 4 Effects of ecosystem disturbances due to anthropogenic loads of acidifying and eutrophic compounds present in atmospheric emissions of objects of the gas industry[a]

Pollutant	Impacting media	Recipients' groups	The nature of existence adverse effects	Direct and indirect effects violations
Totally SO_x+NO_x	Air	Terrestrial plants	Ecotoxicity	Disorders of gas exchange, accumulation in plant tissues. Dry tops. Reduced productivity of forest stands
	Air deposition		Acidification	Leaching of elements from plant tissues
	Soil	Terrestrial plants, soil biota	Acidification	Soil pH lowering
				Nutrient balance disturbance
			Ecotoxicity	The increase in the mobility (toxicity) Al and HM
NO_x	Air	Terrestrial plants	Ecotoxicity	Disorders of gas exchange. Accumulation in plant tissues
	Air deposition		Acidification	Leaching of elements from plant tissues
	Soil	Terrestrial plants, soil biota	Euthrophication	Nutrient balance changing
				Species biodivercity changing
			Acidification	Soil pH decrease
				Nutrient balance disturbance
	Natural waters	Aquatic biota	Euthrophication	Disruption of oxygen exchange. Change in species diversity of biota

[a]Based on the results of the literature review, including: Guderian 1979; Alekseyev 1990; Kasimov 1995; Kindschy et al. 1997; Bobbink et al. 2002; etc.

chemical and ecotoxicological properties of these compounds, the specificity of their transformation in natural environments, the direction of biogeochemical migration depending on the specific landscape conditions and others. Among the most important of the current environmental violations that have local and inter-regions nature, fall ecosystem risks and group effects are summarized in Table 4. In general they can be divided into risks (1) violations of individual functions of ecosystems or their components, (2) changes in productivity and (3) species diversity.

However, the likelihood and severity of such violations are characterized by a high degree of uncertainty, and, above all, due to the multifunctionality of nitrogen and sulfur. As is known, these elements being important biophils, scarce in many natural ecosystems, and their additional revenues from atmospheric deposition often has the effect of "fertilizer" and leads to the increased production of biomass. For example, in the 70–80s of the last century high level of anthropogenic emissions of sulfur oxides fully ensured necessary to obtain high yields of agricultural products S inputs in the agricultural landscapes of Northern Germany, while the forests of Scandinavia at the same time experienced the negative effects of acid rain (Alekseyev 1990). Elevated levels of atmospheric supply of nitrogen, along with the increase of CO_2 emissions into the atmosphere, defined as the main driver of forest productivity in Western Europe (Bashkin and Priputina 2011). This uncertainty possible outcome is also recorded in the risk methodology through the concept of "speculative risks" (Bykov and Porfiriev 2006).

The magnitude of the impact of human activities on biogeochemical processes in the biosphere is manifested in the violation of the natural biogeochemical cycle of nitrogen. Numerous reviews are presented in literature, reflecting different aspects of environmental problems related to anthropogenic transformation of nitrogen cycles at local, regional and global levels (Bashkin 1987; Bobbink et al. 1988, 2002; Semenov 2008; Stepanov 2010). The availability of nitrogen controls many processes in the biosphere, often by capping the rate of primary productivity of biocenoses. Moreover, in autotrophic terrestrial ecosystems, according to agrochemical ideas, nitrogen is the first minimum (Kudeyarov 1989; Nikitishen 2003). This explains the large-scale use in agriculture (and often in the forest sector) mineral nitrogen fertilizers. At the same time, oxides of nitrogen and oxides of sulfur are anthropogenic compounds, determining largely pollution in industrialized and urbanized regions of the world. An additional source of air pollution with nitrogen compounds in these areas can be intensive livestock production, which is associated with the emission of ammonia by soils of pastures and livestock farms.

Polyvalency of nitrogen determines a great variety of its compounds, generated in the atmosphere by chemical transformation, for example, may form toxic to humans and other living organisms of peroxyacetylnitrate (Bashkin and Priputina 2010). Because of the relatively short residence time in the atmosphere, a large part of anthropogenic nitrogen compounds with precipitation or by precipitation enters to terrestrial and aquatic ecosystems, leading to increased levels of atmospheric supply of nitrogen, primarily mineral forms ($N\text{-}NO_3/N\text{-}NH_4$). As a consequence, is almost complete translation of anthropogenic nitrogen compounds in natural cycles of migration, which increases the total flows in the biosphere, the most active compounds of this element.

The study of the biogeochemistry of nitrogen, as a basic element of plant nutrition traditionally conducted in the framework of agrochemical research on crops. Plants assimilate nitrogen as a result of root nutrition in the form of ions NO_3^- and NH_4^+ due to diffusion, adsorption and exchange in the rhizosphere. The intensity of absorption depends on the concentration of these ions in the soil solution and is accompanied by the release into the soil solution by roots, respectively, the bicarbonate ion (HCO_3^-) or organic anions. In addition, it is reporting on the potential uptake by plants organic nitrogen compounds (urea and amino acids), which are transported from the soil solution through the cell membrane or enter the root by mycorrhizal fungi (Semenov 2008). For most plants reflect a diversity of ways of ensuring nitrogen nutrition, which is associated with high heterogeneity and seasonal dynamics of soil conditions within the root zone. Those forms of nitrogen that are most available at a particular point in a particular zone of the soil layer are primarily absorbed.

Atmospheric input of nitrogen of anthropogenic origin in ecosystems in increased amounts compared to background levels has similar environmental impacts to the environment, as agrogenic delivery. In the initial stages of impact, anthropogenic emissions of nitrogen oxides and related additional atmospheric supply of N-NO_3 can be considered as an additional source of nitrogen nutrition of plants in natural ecosystems, leading to increased productivity of plant communities (Bobbink et al. 2002). During "saturation" of natural ecosystems by anthropogenic nitrogen there are multiple environmental violations that depend on a larger number of factors, including regional peculiarities of transformation of nitrogen compounds in the atmosphere, the direction of their biogeochemical migration in natural environments depending on the specific landscape conditions and others.

9.1 Environmental Risks of Anthropogenic Emissions of NO_x on Ecosystems of the Far North

The most promising gas production areas are located in the Northern regions of Russia, which, in addition to the technological and socio-economic characteristics of the operation of these fields, determines the specificity of environmental activities aimed at preventing and reducing potential environmental risks (Samsonov et al. 2007; Rusakova et al. 2009; Bashkin et al. 2012; Markelov et al. 2013; Bashkin 2014).

Nitrogen in tundra ecosystems is the main limiting factor from the point of view of the conditions of supply of ground vegetation, which in combination with poor availability of other biological elements and soil and climatic factors responsible for the low productivity of biocenoses. The main source of nitrogen in these ecosystems—biological fixation, which is associated mainly with algoflora; share biological fixation accounts for about 75 % of the total pool of nitrogen (Archegova and Getzen 1991). The supply of nitrogen from atmospheric deposition to background regions of the Far North is estimated at 2–2.5 kg N/ha/year with predominance of ammonium form.

It is expected that the ecosystems of the North should be sensitive to excess nitrogen, but their productivity, thus, will increase slightly due to the influence of factors such as short growing season and low temperatures of soil root layer. In addition, it is reported on the negative effect of excess nitrates on the soil algal flora (Archegova and Getzen 1991), which may be the cause of reduction of parameters of natural biological nitrogen fixation in tundra ecosystems. It is assumed that the increase in anthropogenic atmospheric nitrogen deposition will increase its fixation in the composition of the biomass of tundra vegetation (mosses, grasses, sedges, etc.) and will also be a change and a reduction in plant species composition. The latter follows from the data of the monitoring observations of the species composition of herbaceous ecosystems in Europe, including sub-Arctic ecosystems. As follows from the data of monitoring of herbaceous plant communities, which in the course of two years or more was observed exceedance of critical loads of nitrogen, one of the consequences of excess nitrogen is the reduction of species diversity accounting areas (Bobbink et al. 2002).

According to several authors (Chapin 1998), most of the information provided in Northern ecosystems "extra" nitrogen will be fixed in the soils in the composition of organo-mineral complex, and only a small amount may be removed from the ecosystem with soil and groundwater runoff. At the same time, for boggy and very wet areas of the Far North is projected rapid removal of anthropogenic nitrogen accumulated in the snow cover during the winter period with melt water in the local water bodies—lakes and swamps (Safonov et al. 2009).

According to expert estimations, rare and available monitoring data (UBA 2004), the allowable income levels, the critical loads of nitrogen for tundra ecosystems and the sub-tundra forests is 5–15 kg N ha^{-1} yr^{-1}. Given these values, a large-scale production of natural gas in areas of the Russian Rar North, including the area of impacts of the production facilities of LLC "Gazprom Dobycha Yamburg", accompanied by intensive anthropogenic emissions of nitrogen oxides, in the long run can pose an increased environmental risk for sustainable development of the region.

Summarizing the presented data, as criteria for the assessment of geo-ecological situation zone "environmental liability" LLC "Gazprom dobycha Yamburg" were evaluated following types of risks (Bashkin et al. 2012).

1. Risks of violations of technological systems as a result of changing thermal insulation properties of vegetative ground cover.
2. Risks of traditional nature use of indigenous numerically small peoples of the North in connection with change of structure of the grassland.
3. Risks of violations of the specific structure of the Northern plant communities.
4. Risks of violations of biospheric functions of ecosystems in the North (environmental, gas exchange, carbon accumulation, biodiversity).

9.2 Analysis of Target Effects in the Evaluation of Geoecological Situation in the Areas of Gas Fields in the Far North

In this case, target effects include environmental priorities of enterprises (regional administrative structures), defining ecological and economic feasibility and validity of measures to reduce risks for geoecological situation.

Historically, the impact of anthropogenic activities on the environment deals primarily with anthropocentric positions, when the quality (status) of the individual components of the natural environment and geoecological situation in general are seen as favorable or not favorable to human health or the performance of its business. Within the concept of risk, this approach is consistent with the general view that risk is a characteristic of the situation when many possible outcomes, there is uncertainty about a particular outcome and at least one of the possibilities is undesirable (Bykov and Porfiriev 2006). Thus, it is expected that favorable outcomes, and depending on the nature of the consequences of risk are distinguished: (1) pure risk, in which all outcomes, apart from maintaining the current situation, are associated with negative consequences (damages); (2) speculative risk, i.e. the risk, the outcomes of which are associated with both negative and positive consequences.

In environmental practice examples of "pure risk" is the environmental pollution by radioactive wastes, dioxins and other persistent and highly toxic pollutants. For compounds of biological elements, including mineral nitrogen compounds, the environmental effects of their receipt in environment—less clear. Thus, an increase in the productivity of many ecosystems (forests, natural pastures and hayfields), which have resource value, as a result of additional income available to plants nitrogen can be regarded as positive (favorable) outcome of exposure to humans, as a consumer of resources. In relation to other recipients (oligotrophic vegetation types and soil microbiota) environmental changes can be considered as adverse disorders, manifested in the change of biodiversity.

In this regard, depending on who may be affected by the implementation of the risk (who is covered by the negative consequences of adverse events), isolated unilateral, bilateral and multilateral risks. Environmental risks associated with natural gas production in the territories of the fields of the Far North, are multilateral risks. As an example, Table 5 shows the principles of an assessment of geoecological situation in the areas of gas and gas condensate fields of the Far North in connection with man-made emissions of nitrogen oxides.

10 Conclusions

Thus, all these classification points, shown in Table 5, are important, since the procedures and methods of analysis and management of different types of risks are fundamentally different. Therefore, at the final step, forecasting and retrospective assessment of geoecological situation spend summation of information on various aspects of risk and comparative analysis of the obtained results with the aim of identifying priority risks, indicating the most sensitive groups of recipients and areas of maximum risk parameters, including, for the operating conditions of the production and technological facilities. These data provide the basis for forecasting and retrospective features geoecological situation.

Table 5 Ranging of geoecological situation in connection with anthropogenic NOx emission in the Far North based on the criterion of risk

Land use type	Recipient or protection object	Probability of CL exceedance	Nitrogen status of ecosystem	Possible damage to recipients or technological units	Risk level	Range of geoenvironmental situation
Especially protected natural areas (regardless from the type of biogeocenoses)	Particularly valuable flora species, and ecosystem diversity	$P < 0.05$	Immobilization	• Virtually absent, • May increase productivity	The risk is virtually nonexistent	Acceptable
		$P = 0.05–0.25$		Perhaps the increase of eutrophic species	Low risk level	Adverse
		$P = 0.25–0.75$	Separation	• Increase productivity, • Possible changes in the species structure	Mean risk level	Dangerous
		$P > 0.75$	Separation or excess	• Species structure disturbance	Increased and high level of risk	
Tundra swamps	Particularly valuable flora species, and ecosystem diversity	$P < 0.05$	Immobilization	• Virtually absent, • May increase productivity of phytocenoses, • The deposition of N in peat thicker	The risk is virtually nonexistent	Acceptable
		$P = 0.05–0.25$			Low risk level	
		$P = 0.25–0.75$	Saturation	• Increase productivity, • Possible changes of species composition of phytocenoses, • Change the degree of flooding	Mean risk level	Adverse
		$P > 0.75$	Saturatuion or excess	• Species structure disturbance	Increased and high level of risk	Dangerous
Tundra swamps	Valuable species of marsh flora, the ecosystem as a regulator of hydrological runoff	$P < 0.05$	Immobilization	• Virtually absent, • May increase productivity of rangelands	The risk is virtually nonexistent	Acceptable

(continued)

Table 5 (continued)

Land use type	Recipient or protection object	Probability of CL exceedance	Nitrogen status of ecosystem	Possible damage to recipients or technological units	Risk level	Range of geoenvironmental situation
		$P = 0.05–0.25$			Low risk level	
		$P = 0.25–0.75$	Saturation	• Increase productivity, • Possible violations of species composition of pastures (reduction in the proportion of lichens)	Mean risk level	Adverse
		$P > 0.75$	Saturation or excess	• Violations of the species structure (reduction in the proportion of lichens) and • Change the degree of flooding	Increased and high level of risk	Dangerous
NTC outside industrial areas and SPZ enterprises (natural tundra ecosystems)	Typical types of tundra flora (lichens, dwarf shrubs etc.)	$P < 0.05$	Immobilization	• Virtually absent, • May increase productivity of phytocenoses	The risk is virtually nonexistent	Acceptable
NTC outside industrial areas and SPZ enterprises (natural tundra ecosystems)	Typical types of tundra flora (lichens, dwarf shrubs etc.)	$P = 0.05–0.25$	Immobilization	• Virtually absent, • May increase productivity of phytocenoses	Low risk level	Acceptable
		$P = 0.25–0.75$	Saturation	• Increase productivity, • Possible violations of the species structure (reduction in the proportion of lichens)	Mean risk level	Adverse

		$P > 0.75$	Saturation or excess	• Violations of the species structure (reduction in the proportion of lichens) and • Change the degree of flooding	Increased and high level of risk	Dangerous
	Technological installation and infrastructure facilities	$P < 0.05$	Immobilization	• No damage, • Remain favorable geotermic properties of soils due to the growth of phytomass stores	The risk is virtually nonexistent	Favorable or acceptable
		$P = 0.05–0.25$			Low risk level	
		$P = 0.25–0.75$	Saturation	• Possible violations of species composition, vegetation cover, • Possible deterioration geotermicheskie properties of soils and • Increase the degree of flooding of territories	Mean risk level	Adverse
		$P > 0.75$	Saturation or excess		Increased and high level of risk	Dangerous

References

Alekseyev, V. A. (1990). *Forest ecosystems and atmospheric pollution*. Leningrad: Nauka Publ. House. 200pp.

Archegova, I. B., & Getzen, M. V. (1991). *Ecological substitution of the management of agrophytocenosis productivity in Eastern-European Tundra*. Leningrad: Nauka Publ. House. 152pp.

Avaliani, S. L., Andrianova, M. M., & Pechennikova, E. V. (1996). *Health risk assessment*. Moscow: Consulting Center on Risk Assessment. 75pp.

Bashkin, V. N. (1987). *Agrogeochemistry of nitrogen*. Moscow: Nauka Publ. House. 189pp.

Bashkin, V. N., Evstaf'eva, E. V., Snakin, V. V., Alyabina, I. O., Galiulin, R. V., Semenov, Y. M., et al. (1993). *Biogeochemical foundations of ecological standardization*. Moscow: Nauka Publ. House. 283pp.

Bashkin, V. N. (2006). *Modern biogeochemistry*. New York: Springer. 400pp.

Bashkin, V. N. (2014). *Biogeochemistry of polar ecosystems in the gas industry impacted zones*. Moscow: Gazprom VNIIGAZ Publishing House. 302pp.

Bashkin, V. N., Kazak, A. S., & Safonov, V. S. (2006). Assessment of ecological risks in impacted zones of gas pipeline Yamal—Centre. *Environmental Protection in Oil and Gas Complex, 3*, 9–14.

Bashkin, V. N., Priputina, I. V., Maklyuk, O. V., & Tankanag, A. V. (2009). Ecological substantiation of regional standards of anthropogenic pollutants. *Science and Technology in the Gas Industry, 2*, 33–40.

Bashkin, V. N., & Priputina, I. V. (2010). *Management of environmental risks at pollutants emission*. Moscow: Gazprom VNIIGAZ Publ. House. 185pp.

Bashkin, V. N., & Priputina, I. V. (2011). Biogeochemical analysis of ecological risks. *Issues of Risk Analysis, 8*(4), 8–21.

Bashkin, V. N., Arno, A. B., Arabsky, A. K., Barsukov, P. A., Priputina, I. V., & Galiulin, R. V. (2012). *Retrospective and forecast of geoecological situation on the gas gondensate fields of the far north*. Moscow: Gazprom VNIIGAZ. 280pp.

Bobbink, R., Bilk, L., & Willems, J. H. (1988). Effects of nitrogen fertilization on vegetation structure and dominance of Brahypodium pinnatum (L.). *Acta Botanica Neerlandica, 37*(2), 231–242.

Bobbink, R., Ashmore, M., Braun, S., Fluckiger, W., et al. (2002). *Empirical critical loads for nitrogen*. Bern: Swiss Agency for Environment.

Bykov, A. A. (2007). Methodology of economic assessment of human life. *Issues of Risk Analysis, 4*(2), 178–191.

Bykov, A. A., & Porfiriev, B. N. (2006). About risk analysis, concepts and risk classification. *Issues of Risk Analysis, 3*(4), 319–337.

Chapin, F. S. (1998). The mineral nutrition of wild plants. *Annual Review of Ecology and Systematics, 11*, 233–260.

Gritsenko, A. I., Maksimov, V. M., Samsonov, P. O., & Akopova, G. S. (2009). *Ecology: Oil and gas*. Moscow: Akademkniga Publ. House. 680pp.

Guderian, R. (1979). *Air contamination*. Moscow: Mir Publ. House.

Hall, J., Ullyett, J., Hornung, M., Kennedy, F., et al. (2001). *Status of UK critical loads and exceedances. Part 1—Critical loads and critical loads maps: Update to January 1998 report.* Report prepared under DEFRA/NERC Contract EPG1/3/185 (http://critloads.ceh.ac.uk).

Kasimov, N. S. (Ed.). (1995). *Ecogeochemistry of urban ecosystems*. Moscow: Moscow State University Publ. House. 336pp.

Kindschy, J. W., Kraft, M., & Carpenter, M. (1997). *Hazardous materials and waste management*. Point Areana, CA: Solano Press Books. 345pp.

Kolesnikov, E. Y. (2007). Practice of safety certificates development. *Issues of Risk Analysis, 4*(2), 106–128.

Kolesnikov, E. Y. (2008). About methodological support risk assessment flammable objects. *Issues of Risk Analysis, 5*(2), 8–25.

Kosheleva, I. T., & Tolstukhina, A. S. (1964). On the issue of cultivation of soils of Northern Prio'e. *Eurasian Soil Science, 12*, 34–39.

Kowalski, V. V. (1974). *Geochemical ecology*. Moscow: Nauka Publ. House. 300pp.

Kudeyarov, V. N. (1989). *Cycle of nitrogen in soil and efficiency of nitrogen fertilizers*. Moscow: Nauka Publ. House. 213pp.

Lesnykh, V. V. (1999). *Analysis of risk and the recovery mechanisms of damage by accidents at power plants*. Novosibirsk: Nauka Publ. House. 251pp.

Makunina, A. A. (1985). *Physical geography of USSR*. Moscow: Moscow State University Publ. House. 296pp.

Markelov, V. A., Andreev, J. P., & Kobylkin, D. N. (2013). *Sustainable development of gas industry*. Moscow: Nedra. 203pp.

Methodical Recommendations on Risk Analysis and Management. (1999). Bykov, A. A. (Ed.). Moscow: Ankil Publ. House, 72pp.

Murzin, N. V., Lystsov, V. N., & Bykov, A. A. (2006). *Guidelines of the estimation of ecological risk for biological components of ecosystems (including human health) and ecological-economical damages for the environment in the areas of storage and destruction of chemical weapons*. Moscow: Ecobizopasnost' Publ. House.

Natural Conditions and Resources of USSR: The Western Sibiria. (1963). Moscow: Publ. House of Academy of Sciences of USSR.

Nazarov, A. D. (1977). Fauna of bogs. In M. I. Neystadt (Ed.), *Scientific principles of the West Siberia bogs use* (pp. 148–160). Moscow: Nauka Publ. House.

Night, K. (2006). Risk management. From decision to realization. *Issues of Risk Analysis, 3*(4), 383–387.

Nilsson, J., & Grennfelt, P. (1988). *Critical loads for sulfur and nitrogen.* NORD Status Report 1988:15. Copenhagen, Denmark: Nordic Council of Ministers.

Nikitishen, V. I. (2003). *Ecological-agrochemical basis of balanced use of fertilizers in adaptive agriculture*. Moscow: Nauka Publ. House. 183pp.

Onishchenko, G. G., Novikov, S. M., Rakhmanov, Y. A., Avaliani, S. L., & Bushueva, K. A. (2002). *Principles of risk assessment for health when exposed to chemicals, polluting the environment*. Moscow: Institute of MES. 408pp.

Peti, M. (2004). Scientific uncertainties and make decision. In: M. Peti (Ed.), *Proc. of World Conference on Climate Change, Moscow*, Sept. 29–Oct. 3, 2004 (pp. 482–487).

Posch, M., Hettelingh, J.-P., & Slootweg, J. (2007). *Critical loads and dynamic modeling of nitrogen*. CCE Progress Report. Bilthoven, The Netherlands.

Priputina, I. V., & Bashkin, V. N. (2008). Analysis of geoecological risks of the emission of nitrogen oxides during the exploitation of gas fields of the Far North. *Environmental Protection in Oil and Gas Complex, 8*, 23–28.

Protsenko, A. N. (2006). About main principles and mechanisms of the management of regional safety. *Issues of Risk Analysis, 3*(3), 256–291.

Revich, B. A., Avaliani, S. L., & Tikhonova, G. I. (2004). *Economical epidemiology*. Moscow: Academy Publ. House. 384pp.

Risk: Analysis, Perception, Management. (1992). London: Royal Society of London, 200pp.

Rusakova, V. V., Kazak, A. S., Bashkin, V. N., Lesnykh, V. V., & Galiulin, R. V. (2009). *Management of ecological risks in gas industry*. Moscow: VNIIGAZ Publ. House. 200pp.

Safonov, V. S., Volkov, A. N., & Kovalev, S. A. (2009). *Substitution of criterias of negative impacts of gas compressor station on population and environment*. Moscow: VNIIGAZ Publ. House. 72pp.

Samsonov, R. O., Kazak, A. S., Bashkin, V. N., & Lesnykh, V. V. (2007). *System analysis of geoecological risks in gas industry*. Moscow: Nauchniy Mir Publ. House. 271pp.

Semenov, V. M. (2008). Modern problems and perspectives of the agrochemistry of nitrogen. *Problems of Agrochemistry and Ecology, 1*, 55–63.

Shumilova, L. B. (1969). Bog regions of the Western Sibiria in the frame of Tyumenskaya Oblast. *Reports of the Institute of Geography of Sibiria and Far East, 23*, 12–17.

Sobol, I. M. (1985). *Method of Monte-Carlo*. Moscow: Nauka Publ. House. 64pp.
Soils of the USSR. (1979). V. V. Dobrovolsky (Ed.). Moscow: Prosveshenie Publ. House, 380pp.
Stepanov, A. L. (2010). N_2O and ecological problems. *Priroda, 2*, 35–40.
UBA. (1996). *Manual for methodologies and criteria for mapping critical levels/loads.* Text 71.UBA.
UBA. (2004). *Manual on methodologies and criteria for modelling and mapping critical loads and levels and air pollution effects, risks and trends*. Chapter 5.5. www.icpmapping.org.

Biogeochemical Approaches for Managing Geoenvironmental Risk of Hydrocarbons Pollution in Disturbed Soils

Rauf V. Galiulin and Vladimir N. Bashkin

Abstract The laboratory tests carried out in the conditions of *in vitro* experiment with new biological means of a soil cover remediation are considered as biogeochemical approaches for managing geoenvironmental risk of pollution by hydrocarbons—gas condensate and oil in various climatic zones, including tundra. For the assessing soil remediation efficiency the enzyme activity analysis are used and the relevant full degradation of hydrocarbons is calculated. Such approach allows us to obtain the correct information for realization of a soil remediation *in situ* in perspective. So, the comparative assessment of degradation of gas condensate and oil in a soil under application of new biological preparations (Bioros and Piksa) showed that degradation of gas condensate in soil, for example, under Bioros action was faster than degradation of oil. After introduction of Piksa to soil the process of oil degradation was much faster. The activity of catalase and dehydrogenase enzymes increased with enhanced quantity of biological preparations used for oil contaminated soil remediation.

Keywords Disturbed soil • Illuvial horizon • Pollution • Gas condensate • Oil • Degradation • Biological preparations • Enzymatic activity

1 Introduction

The most widespread type of anthropogenic impact on the tundra as on a unique natural zone, which most part lies beyond the North Polar Circle (at latitude ± 66°33′44″) is production and transport of gas, gas condensate and oil. It is

R.V. Galiulin (✉)
Institute of Basic Biological Problems of Russian Academy of Sciences, Pushchino, Moscow Region 142290, Russian Federation
e-mail: rauf-galiulin@rambler.ru

V.N. Bashkin
Institute of Physicochemical and Biological Problems of Soil Science of Russian Academy of Sciences, Pushchino, Moscow Region 142290, Russian Federation

Institute of Natural Gases and Gas Technologies—Gazprom VNIIGAZ LLC, Razvilka, Moscow Region 142719, Russian Federation

V.N. Bashkin (ed.), *Biogeochemical Technologies for Managing Pollution in Polar Ecosystems*, Environmental Pollution 26, DOI 10.1007/978-3-319-41805-6_15

known that gas condensate and oil represent the mixtures of liquid hydrocarbons of various classes (paraffines, naphthenes, arenes). At the same time a gas condensate drops out from gas solution under pressure reduction (gas recovery from stratum). It has lower density (0.7–0.8 g/cm^3) compared to oil (0.8–1.1 g/cm^3) and contains fewer heteroatomic compounds (resins and asphaltenes, including apart from carbon and hydrogen atoms sulfur, nitrogen and oxygen atoms). Production and transport of gas condensate and oil lead to their spills caused by accidents under various circumstances. To number of the regions covering a greater or lesser extent of zone of the tundra and where recently emergency pollution by hydrocarbons of a soil cover was noted are belonged the Nenets Autonomous Okrug and the Republic of Komi. So, in 2012, at the Nenets Autonomous Okrug the depreservation of prospecting well on an oil field happened to an oil spill (more than 1000 m^3) on the soil with the area of contamination of 2.8 ha (Dmitrievskaya et al. 2012) as well as there was an emergency oil leakage (about 130 m^3) with the area of soil contamination about 0.1 ha (Dmitrievskaya et al. 2013a). In 2014, also in the Nenets Autonomous Okrug, owing to depressurization of the pipeline there was an oil spill on the soil (Dmitrievskaya et al. 2015). In 2008, the depressurization of a condensate pipeline at a gas processing plant in the Republic of Komi resulted in the leakage of about 25 m^3 of condensate on a land relief (Ovanesyants et al. 2008). Two years later, in the same region from the infield oil pipeline about 150 m^3 of oil with the area of soil contamination 6.3 ha have flowed out (Ovanesyants et al. 2010). In 2013, also in the Republic of Komi, the rush of the pipeline was resulted by oil spill on the soil (Dmitrievskaya et al. 2013b).

The contamination by liquid hydrocarbons reduces the soil quality, lands are taken out from the agricultural fund. For example, the site on the territory of a booster compressor station had no vegetation and "oil" layer in the soil profile due to long-lasting penetration of gas condensate from a vent stack (Galiulin et al. 2014). According to (Koronelly 1996), the level of soil contamination by hydrocarbons of 5 % from the soil mass (50 g/kg) does not allow to use it for agricultural purposes. There are examples of biogeochemical monitoring of oil-contaminated soils carried out during 3–10 years, which shows that natural remediation is a long process (Kireeva et al. 2002). Thus, the search for and testing of efficient remediation methods for oil- and gas condensate-contaminated soils based on the destructive capacity of hydrocarbon-oxidizing microorganisms—bacteria, yeasts or filamentous fungi—used in the form of biological preparations is very important. The former is lyophilically dried (under low temperature and in vacuum) microorganism biomass, the latter is compositions made by accelerated fermentation of turf-excrement or turf-manure and other mixtures and enriched by hydrocarbon-oxidizing microflora and nutrient substances. Testing of biological preparations as remediation means is reasonable to carry out as *in vitro* experiment, where the impact of different factors on gas condensate and oil hydrocarbons degradation can be simulated (quantity, temperature, etc.) and the required information for further *in situ* studies can be quickly obtained.

The work is aimed at investigation of gas condensate and oil degradation at conditions of *in vitro* experiment in a physically disturbed soil under action of two new biological preparations—Bioros and Piksa. It is known that physical disturbance, in particular, of tundra soils, i.e. deprivation of their vegetable cover and top organogenic layer with an exit of the mineral horizons to a day surface, happens at journey of the equipment connected with geological exploration implementation, drilling of wells and arrangement of crafts on oil and gas production.

2 Materials and Methods

Bioros is based on two physiological groups of microorganisms—*Rhodococcus* sp. bacteria and *Candida* sp. yeast, total quantity 10^{10} cells/g (Akopova 2008; Listov et al. 2008). Used Piksa (Premium) is made by accelerated fermentation of turf-manure mixture and enriched by hydrocarbon-oxidizing microorganisms in the quantity of 10^6 cells/g and nutrient substances (Sementsov 2006). The stated quantity of these microorganisms in the Piksa is considered sufficient for self-reproduction and impact on neighboring populations (Koronelly 1996).

The investigation of gas condensate and oil hydrocarbons degradation was carried out on an averaged sample of illuvial horizon (50–90 cm layer) of the physically disturbed soil (heavy clay loam, pH_{H2O} 6.2) (Figs. 1 and 2). The soil sample was treated with gas condensate and oil in the amount of 50 g/kg, and after that Bioros was introduced (0.1 and 0.5 g/kg). During the other test Piksa was introduced (50 and 100 g/kg) to the soil treated with oil (50 and 100 g/kg). The Bioros was introduced to the soil in the form of suspension made by solution homogenization of ammophoska (6 g/l) performed by air barbotage for 3 h. Soil samples treated with gas condensate, oil and biological preparations incubated in plastic reservoirs (250 ml volume) under constant humidity—70 % from full moisture capacity: first 20 days—under temperature +8 °C and other 20 days—under +18 °C. The latter was connected with simulation of yearly temperature changes in the studied soil

Fig. 1 Non-disturbed soil, i.e. with existing vegetable cover and top organogenic layer

Fig. 2 Physically disturbed soil, i.e. deprived of vegetable cover and top organogenic layer with exit of illuvial horizon to day surface

layer in May-July. Here under the full moisture capacity of a soil is understood as that greatest number of moisture which contains in its at full saturation of a pores.

On the 10th and 40th day, the content of gas condensate and oil hydrocarbons was analyzed by infrared spectrometry using IKN-025 concentration meter. For this purpose 50 ml of carbon tetrachloride (5 min) were used for extraction 1 g of soil sample lot by Ekros-8000 extractor. After settlement (10 min) the extract was fed to the chromatographic column with Al_2O_3 and the content of gas condensate and oil hydrocarbons was analyzed using the concentration meter. To confirm the microbiological nature of degradation, in particular of oil hydrocarbons, on the 40th day the activity of catalase (ml O_2/(min · g)) and dehydrogenase (mg 2,3,5-triphenylformazan/(g · day)) enzyme activities was measured by patented gas metric and spectrophotometric methods respectively (Bashkin et al. 2010a, b).

The statistic processing of results was performed at confidence interval adopted for geoecological studies for an average value of different variants calculated at the significance level $P_1 = 0.05$. The results of the analysis of the content of gas condensate and oil hydrocarbons were used to calculate the time of their practically full degradation, i.e. by 99% (T_{99}) under the exponential relation: $y = e^{-kt}$, where y—residual hydrocarbons content at time t, related to the initial; e—base of the natural logarithm; k—hydrocarbon degradation velocity constant. The corresponding formula for calculation is as follows: $T_{99} = ln\ 100/k$.

3 Conception of Hydrocarbon Degradation in Illuvial Horizon of Disturbed Soil Under Biological Preparations Action

The use of illuvial horizon of a disturbed soil for investigation of gas condensate and oil hydrocarbons degradation was not accidental. The studies (Kalachnikova et al. 1985) carried out on podzolic illuvial-humus soil showed that for a year after treatment oil penetrated to the depth of 50 cm, passed illuvial horizons and reached the groundwater table. Observations (Pikovsky et al. 1985) revealed that in the earth storage designed for spilled oil sequestration a powerful inter-soil flow of hydrocarbons moving to the place of ground waters off-loading was identified in silty-gley soil profile. The upper boundary of the flow was identified at 50–60 cm depth and the lower boundary linked with the groundwater table. Thus, studies of illuvial horizon of soil are of certain scientific interest, since, on the one hand, they allow to estimate gas condensate and oil hydrocarbons degradation under conditions of 1–2 orders smaller quantity of microorganisms of various physiological groups compared to upper soil horizons. On the other hand, it allows the researcher to identify better the remediation capacity of tested biological preparations. As for hydrocarbons microbiological degradation, this process performed by, in particular, *Rhodococcus* bacteria included into Bioros involves absorption of substances by hydrophobization of the cell wall implemented through biosynthesis of specific compounds—lipophil glycol-, peptide- and peptideglycollipids (Koronelly 1996). In case of a direct contact of bacteria with a hydrocarbon film the latter penetrate into the cell by passive diffusion—gradual penetration into the cell wall—and reach enzymes on membranes. Along with molecular-diffuse penetration of hydrocarbons through the surface of the cell wall, they can penetrate through special ultramicroscopic pores as well. Such channels filled with electron-dense (granular) substance were first found in yeasts, one strain of this physiological group of microorganisms is included into Bioros as a second active component.

The analysis of catalase and dehydrogenase activity carried out during the investigation was caused by their direct participation in hydrocarbons degradation. Catalase accelerates hydrocarbons oxidation by hydrogen peroxide, destroying last to oxygen necessary for this reaction, and dehydrogenase catalyzes hydrogen abstraction from hydrocarbon oxidation products molecules (dehydration reaction). The involvement of hydrogen peroxide in this biochemical reaction is caused by its generation in the process of microorganisms breathing and hydrocarbon oxidation.

The use of exponential relation for calculation of the time of practically full hydrocarbon degradation (T_{99}) under action of biological preparations was also logical. It was observed (Vodopyanov et al. 2004) that the oil-contaminated soil experienced the exponential reduction of phytotoxicity level, which usually coincides with the decrease of hydrocarbons due to their microbiological degradation.

4 Results and Discussion

The time of practically full hydrocarbon degradation of gas condensate hydrocarbons reduced by 46 and 5 days respectively compared to oil hydrocarbons at treatment of a soil sample by different quantities of Bioros (0.1 and 0.5 g/kg) which is caused by lower content of arenes, resins and asphaltenes that are less accessible for microorganisms than paraffines and naphthenes in the former (Table 1).

Table 1 Time of practically full degradation (T_{99}) of gas condensate and oil hydrocarbons in a sample of soil illuvial horizon (50–90 cm layer) under Bioros biological preparation action

Variant	T_{99}
Gas condensate, 50 g/kg + Bioros, 0.1 g/kg	125
Gas condensate, 50 g/kg + Bioros, 0.5 g/kg	56
Oil, 50 g/kg + Bioros, 0.1 g/kg	171
Oil, 50 g/kg + Bioros, 0.5 g/kg	61

Table 2 Time of practically full degradation (T_{99}) of oil hydrocarbons in a sample of soil illuvial horizon (50–90 cm layer) under Piksa biological preparation action

Variant	T_{99}
Oil, 50 g/kg	329
Oil, 50 g/kg + Piksa, 50 g/kg	184
Oil, 50 g/kg + Piksa, 100 g/kg	69
Oil, 100 g/kg	1150
Oil, 100 g/kg + Piksa, 50 g/kg	658
Oil, 100 g/kg + Piksa, 100 g/kg	288

Soil treatment by Piksa (50 and 100 g/kg) reduced the time of oil hydrocarbons degradation process in case of oil concentration 50 g/kg by 1.8 and 4.8 times, 100 g/kg—by 1.7 and 4.0 times (Table 2).

The activity of catalase and dehydrogenase increased with the growing quantity of used biological preparations at different levels of soil contamination with oil (50 and 100 g/kg), in case of Piksa by 9–27 and 4.7–15.6 times, Bioros—by 7–31 and 3.7–18.8 times respectively (Table 3).

Enzymatic diagnostics of gas condensate hydrocarbons degradation process performed earlier *in situ* conditions showed that under action of different quantities of Piksa (4–16 kg/m^2) the activity of catalase and dehydrogenase of heavy clay loam soil increased in average by 1.9–2.8 and 5.7–8.9 times (Galiulin et al. 2014) respectively.

The increased enzymatic activity at application of biological preparations confirms the microbiological nature of gas condensate and oil hydrocarbons degradation. Studies (Teranishi et al. 1974) have shown that yeasts that grew on hydrocarbons have a direct connection between the increased quantity of peroxisomes (organelles in cell cytoplasm) and increased activity of catalase with this enzyme. However the observed reduced enzymatic activity at increased soil pollution level in several cases has different reasons, including development of anaerobic conditions, direct inhibition of catalytic activity of enzymes or delay of their synthesis by microorganisms at suppression of the latter growth under the impact of oxidized hydrocarbon products, such as hexadecyl spirit, palmic, benzoic, salycilic acids, etc.

Thus, biogeochemical approaches for managing geoenvironmental risk of pollution of liquid hydrocarbons (gas condensate and oil) in tundra zone should include the tests in the conditions of *in vitro* experiment of new biological means of soils remediation. Such an approach allows us to obtain the correct information for further *in situ* remediation of polluted soils. Efficiency of a soil remediation *in situ* will be defined, first of all, by prompt acting of delivery of biological means to the place of emergency flood from place of their direct production. Of course this would be

Table 3 Catalase and dehydrogenase activities of soil illuvial horizon (50–90 cm layer) contaminated by oil under introduction of Piksa and Bioros biological preparations

Variant	Activity of	
	Catalase, ml O_2/(min·g)	Dehydrogenase, mg 2,3,5-triphenylformazan/(g·day)
Oil, 50 g/kg	0.1	0.13
Oil, 50 g/kg + Piksa, 50 g/kg	1.5	0.74
Oil, 50 g/kg + Piksa, 100 g/kg	2.7	1.38
Oil, 50 g/kg + Bioros, 0.1 g/kg	3.1	2.18
Oil, 50 g/kg + Bioros, 0.5 g/kg	2.9	2.45
Oil, 100 g/kg	0.1	0.15
Oil, 100 g/kg + Piksa, 50 g/kg	0.9	0.71
Oil, 100 g/kg + Piksa, 100 g/kg	2.2	2.34
Oil, 100 g/kg + Bioros, 0.1 g/kg	0.7	0.55
Oil, 100 g/kg + Bioros, 0.5 g/kg	1.1	1.43

more rational to have a certain stock of biological means on objects of oil and gas branch in order that permit immediately to use them in emergency situations.

5 Conclusions

The laboratory tests carried out in the conditions of *in vitro* experiment with new biological means of a soil cover remediation are considered as biogeochemical approaches for managing geoenvironmental risk of pollution by hydrocarbons—gas condensate and oil in various climatic zones, including tundra. For the assessing soil remediation efficiency the enzyme activity analysis are used and the relevant full degradation of hydrocarbons is calculated. Such approach allows us to obtain the correct information for realization of a soil remediation *in situ* in perspective. So, the comparative assessment of degradation of gas condensate and oil in a soil under application of new biological preparations (Bioros and Piksa) showed that degradation of gas condensate in soil, for example, under Bioros action was faster than degradation of oil. After introduction of Piksa to soil the process of oil degradation was much faster. The activity of catalase and dehydrogenase enzymes increased with enhanced quantity of biological preparations used for oil contaminated soil remediation.

References

Akopova, G. S. (2008). Biopreparation cleaning of technogenic environments contaminated by hydrocarbons. *Gas Industry, 6*, 69–71.

Bashkin, V. N., Bukhgalter, E. B., Galiulin, R. V., Konyaev, S. V., Kalinina, I. E., & Galiulina, R. A. (2010a). *Control method for cleaning of soils contaminated by hydrocarbons and neutralization of hydrocarbons sludge by catalase activity analysis*. RU Patent 2387995.

Bashkin, V. N., Bukhgalter, E. B., Galiulin, R. V., Konyaev, S. V., Kalinina, I. E., & Galiulina, R. A. (2010b). *Control method for cleaning of soils contaminated by hydrocarbons and neutralization of hydrocarbons sludge by dehydrogenase activity analysis*. RU Patent 2387996.

Dmitrievskaya, E. S., Krasil'nikova, T. A., & Markova, O. A. (2012). Environmental pollution and radiation situation on the Russian Federation territory in April 2012. *Meteorology and Hydrology, 7*, 104–111.

Dmitrievskaya, E. S., Krasil'nikova, T. A., & Markova, O. A. (2013a). Environmental pollution and radiation situation on the Russian Federation territory in October 2012. *Meteorology and Hydrology, 1*, 100–107.

Dmitrievskaya, E. S., Krasil'nikova, T. A., & Markova, O. A. (2013b). Environmental pollution and radiation situation on the Russian Federation territory in May 2013. *Meteorology and Hydrology, 8*, 101–107.

Dmitrievskaya, E. S., Krasil'nikova, T. A., & Markova, O. A. (2015). Environmental pollution and radiation situation on the Russian Federation territory in December 2014. *Meteorology and Hydrology, 3*, 109–115.

Galiulin, R. V., Galiulina, R. A., & Bashkin, V. N. (2014). Reclamation of soil polluted by gas condensate using peat compost. *Solid Fuel Chemistry, 48*(5), 320–322.

Kalachnikova, I. G., Maslivets, T. A., Oborin, A. A., Ogloblina, A. I., & Pikovsky, YU. I. (1985). Transformation of oil in podzolic soils of Middle Ob river basin. *Migration of contaminating substances in soils and adjoining environments*. Leningrad: Gidrometeoizdat Publishing House, 74–80pp.

Kireeva, N. A., Novoselova, E. I., & Onegova, T. S. (2002). Catalase and dehydrogenase activity in soils contaminated by oil and oil products. *Agrochemistry, 8*, 64–72.

Koronelly, T. V. (1996). Principles and intensification methods of biological degradation of hydrocarbons in the environment (review). *Applied Biochemistry and Microbiology, 32*, 579–585.

Listov, E. L., Akopova, G. S., & Balakirev, I. V. (2008). Technology optimization of «Bioros» preparation production on experimental installation of VNIIGAZ LLC. *Protection of the Environment in Oilgas Complex, 8*, 9–13.

Ovanesyants, A. M., Krasil'nikova, T. A., & Ivanov, A. B. (2008). Environmental pollution and radiation situation on the Russian Federation territory in June 2008. *Meteorology and Hydrology, 9*, 102–106.

Ovanesyants, A. M., Krasil'nikova, T. A., & Ivanov, A. B. (2010). Environmental pollution and radiation situation on the Russian Federation territory in April 2010. *Meteorology and Hydrology, 7*, 104–112.

Pikovsky, Y. I., Veselovsky, V. A., Vshivtsev, V. S., Ernestova, L. S., & Biya, L. A. (1985). Geochemical and ecological study of oil flows in moist subtropics zone. In Y. I. Pikovsky (Ed.), *Migration of contaminating substances in soils and adjoining environments* (pp. 64–69). Leningrad: Gidrometeoizdat Publishing House.

Sementsov, A. Yu. (2006). *«Piksa» Supercompost use for urban soils rehabilitation. Methodical recommendations*. Moscow: VNIIA Publishing House. 32pp.

Teranishi, Y., Kawamoto, S., Tanaka, A., Osumi, M., & Fukui, S. (1974). Induction of catalase activity by hydrocarbons in *Candida tropicalis* pK 233. *Agricultural and Biological Chemistry, 38*, 1221–1225.

Vodopyanov, V. V., Kireeva, N. A., & Tarasenko, E. M. (2004). Phytotoxicity of oil contaminated soils (mathematical modeling). *Agrochemistry, 10*, 73–77.

Biogeochemical Technology for Monitoring of Cleaning of Soil Polluted by Gas Condensate and Neutralization of Its Sludge by Means of Enzyme Activity Analysis

Rauf V. Galiulin, Vladimir N. Bashkin, and Rosa A. Galiulina

Abstract The biogeochemical technology for cleaning of soil polluted by gas condensate and neutralization of its sludge by means of enzyme (catalase and dehydrogenase) activity analysis is considered. This technology includes selection of various samples (the soil of background uncontaminated site, biological means, the soil of site polluted by gas condensate and its sludge, the soil of site polluted by gas condensate, but with addition of biological means and its sludge, also with addition of biological means) and enzyme activity analysis in these samples. In this case we can judge about beginning of the process of cleaning and biological neutralization of polluted samples on a basis of increasing the enzyme activity of samples concerning enzyme activity of samples without addition of biological means, and about ending the process of cleaning and neutralization of samples judge on alignment of enzyme activity of the samples with enzyme activity of soil samples from background uncontaminated site or itself biological means.

Keywords Soil pollution • Gas condensate • Gas condensate sludge • Biological means • Cleaning • Neutralization • Enzyme activity

R.V. Galiulin (✉) • R.A. Galiulina
Institute of Basic Biological Problems of Russian Academy of Sciences,
Pushchino, Moscow Region 142290, Russian Federation
e-mail: rauf-galiulin@rambler.ru

V.N. Bashkin
Institute of Physicochemical and Biological Problems of Soil Science of Russian Academy of Sciences, Pushchino, Moscow Region 142290, Russian Federation

Institute of Natural Gases and Gas Technologies—Gazprom VNIIGAZ LLC,
Razvilka, Moscow Region 142719, Russian Federation

V.N. Bashkin (ed.), *Biogeochemical Technologies for Managing Pollution in Polar Ecosystems*, Environmental Pollution 26, DOI 10.1007/978-3-319-41805-6_16

1 Introduction

It is known that a gas condensate represents the mixture of liquid hydrocarbons (pentane + highest homologs) which is exude from natural gases at operation of a gas condensate deposit as result of bed pressures decrease (while pressure of the beginning of condensation is lower) and temperature. This substance consists from petrol (boiling interval from 30–80 to 200 °C) and kerosene components (200–300 °C) and, to a lesser extent, more highly boiling components. In a gas condensate composition various sulfurous compounds, including hydrogen sulfide are occurred. There is an unstable gas condensate, that is primary product, which is exude from gas of a gas-condensate deposit in trade conditions, and a stable gas condensate from which the dissolved gases (methane-butane fraction) are removed. A gas condensate is valuable natural raw material for receiving aromatic hydrocarbons (benzene, toluene, xylols), olefins and other monomers with their subsequent processing in plastics, synthetic rubbers, fibers and pitches, and also for production of automobile gasoline, jet, diesel and boiler fuel.

In the gas industry, as well as in any other technogenic sphere aren't excluded accidents, which quantity can't be planned, and their 100 %-avoiding is almost impossible. Accidents are shown in the form of gas condensate spills accompanied in some cases with fires, and happening, for example, at a stage of carrying out geology prospecting works, a development stage of gas-condensate fields, and also on delivery the substance to a consumer by means of gas condensate pipelines or bulk transport (Andreev et al. 2011). At accidents the big mass of gas condensate considerably exceeding its maximum permissible concentration arrive to the environment and pollution can proceed before restoration of normal technological process or elimination of an accident. So, in the Republic of Komi, Russian Federation, through which territory passes the Polar Circle, owing to depressurization of a gas condensate pipeline at a gas-processing plant on a land relief about 25 m^3 of gas condensate is pour out (Ovanesyants et al. 2008). At journey of the cargo train through the Kirov region, RF, there was a derailment of 32 tanks with a gas condensate that led to its flood and ignition (Dmitrevskaya et al. 2014).

Soil pollution by gas condensate not only for a long time stops an agricultural turn, but also creates a danger of pollution of the surface and underground waters used for the economic and drinking purposes. Especially serious ecological situation develops when production objects of the gas industry are located in densely populated areas. Emergency pollution of a soil by gas condensate makes negative impact on the human beings due to volatilization from its surface of the gases dissolved in a gas condensate. In this case sharp intoxication by some volatile components of gas condensate leads to a lethal outcome, owing to heart violations and oedema of the lungs (Andreev et al. 2011). In this regard as preventive measures there has to be an expeditious carrying out evacuation of a population at emergency spill of gas condensate in connection with threat of intoxication or fire, and also implementation of systematic control of an ecological situation in the locations of production objects of the gas industry by the analysis of the content of gas condensate in environment and comparison to its maximum permissible concentration. Meanwhile, the gas condensate sludge arriving from linear part of the main gas pipelines and from vessels of a high pressure of compressor stations at their purges and accumulated in barns also represents risk, in connection with its volatilization, pollution of atmospheric air, intoxication of person and emergence of fire.

2 Conception of the Biogeochemical Technology for Cleaning of Soil Polluted by Gas Condensate and Neutralization of Its Sludge by Means of Enzyme (Catalase and Dehydrogenase) Activity Analysis

As it was shown in our previous researches the cleaning of soil from gas condensate and neutralization of its sludge is effectively made by means of such biological means as the Piksa biocompost received by a fermentation of peat-manure mixture and enrichment by hydrocarbon-oxidant microorganisms in number of 10^6 cell/g and nutrients (Sementsov 2006). The above quantity of microorganisms in the biocompost is considered sufficient for self-reproduction of their population, as one of important conditions of the effective cleaning of soil polluted by gas condensate and neutralization of its sludge happening by microbiological degradation of hydrocarbons of this substance (Koronelly 1996).

Efficiency of cleaning of soil from gas condensate and neutralization of its sludge is estimated by means enzyme (catalase and dehydrogenase) activity analysis, and making a basis of the methods protected by patents of the Russian Federation (Bashkin et al. 2010a, b). The fact of process of soil cleaning from gas condensate and neutralization of its sludge under the influence of biocompost is proved by increase of activity of enzymes—catalase and dehydrogenase, as products of the hydrocarbon-oxidant microorganisms (bacteria, yeasts and filamentous fungi) (Koronelly 1996). In this case the mechanism of microbiological degradation of hydrocarbons consists in absorption of these substances by means of a hydrophobization of the cell wall of a microorganism realized through biosynthesis of specific compounds—lipophilic glycol-, peptide- and peptideglycollipids. In case of a direct contact, for example, of bacteria with a hydrocarbon film the latter penetrate into a cell by passive diffusion—gradual penetration of cell wall—and reach enzymes on membranes. Along with molecular-diffuse penetration of hydrocarbons through the surface of cell wall, they can penetrate through special ultra-microscopic pores as well. Such channels filled with electron-dense (granular) substance were first found in yeasts.

Use in particularly of a catalase activity for an assessment of efficiency of a site soil cleaning from gas condensate and neutralization of its slime was not casual as this enzyme is directly involved in degradation of gas condensate hydrocarbons. Catalase accelerates hydrocarbons oxidation by hydrogen peroxide, destroying last to oxygen necessary for this reaction. The involvement of hydrogen peroxide in this biochemical reaction is caused by its generation in the process of microorganisms breathing and hydrocarbon oxidation. So, studies (Teranishi et al. 1974) have shown that yeasts grew on hydrocarbons have a direct connection between the increased quantity of peroxisomes (organelles in cell cytoplasm) and increased activity of catalase, which is localized there.

Use of activity of other enzyme—dehydrogenase for an assessment of efficiency of a site soil cleaning from gas condensate and neutralization of its slime was not also casual as this enzyme is directly involved in degradation of gas condensate hydrocarbons. Dehydrogenase catalyzes a hydrogen abstraction from molecules of hydrocarbon oxidation products, the so-called dehydration reaction.

3 Biogeochemical Technology of Cleaning of Soil Polluted by Gas Condensate and Neutralization of Its Sludge by Means of Enzyme Activity Analysis

The biogeochemical technology of cleaning of soil polluted by gas condensate and neutralization of its sludge is as follows: after addition of biological means into the soil polluted by gas condensate and in its sludge select in dynamics (every 10 days) samples of various variants (in six multiple frequencies), namely: soil from background uncontaminated site, biological means, soil from site polluted by gas condensate and its sludge, soil from site polluted by gas condensate, but with addition of biological means and gas condensate sludge, also with addition of biological means.

Then, in case of catalase enzyme activity, in these samples given to an air-dry state determine enzyme activity by a gas-metric method, that is by the device consisting of gas-meter (1) arranged by principle of the Warburg's vessel, tap (2), catalase reactor (3) and cranked vessel (4) (Khaziev 1976) (Fig. 1).

For the purpose of catalase enzyme activity analysis, 1 g of sample, separately from each above-named variant and 0.1 g of thin crushed calcium carbonate ($CaCO_3$) place consecutively in a catalase reactor and mixture (b) mix up stirring, and in a cranked vessel flow 5 ml of 3 % water solution of hydrogen peroxide (H_2O_2) (c). Further the gas-meter is pressurized, using vacuum greasing, by means connection of a cranked vessel with a catalase reactor and closing of a tap. Then turn of a cranked vessel on 180° and its content is merged in a catalase reactor. It starts the biochemical reaction with release of oxygen (O_2), which quantity is fixed on decrease to column level with the painted water (a) in the right part of the gas-meter by a stop watch within 1 min and express in terms of ml O_2/(min · g):

$$2H_2O_2 = O_2 + 2H_2O$$

As for analysis of the dehydrogenase enzyme activity, in this case in the air-dry samples the given activity is determined by device in form of the modified Erlenmeyer's flask (1) with a cranked branch (2) (Fig. 2).

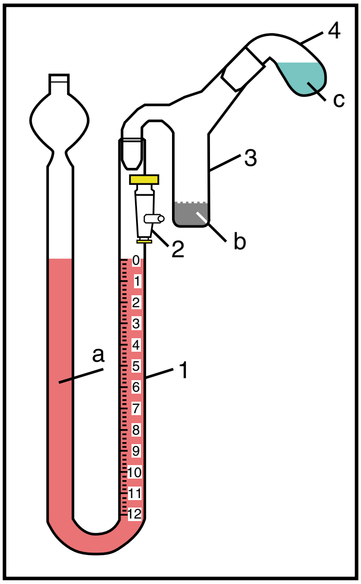


Fig. 1 Device for catalase enzyme activity analysis of samples at cleaning of soil polluted of gas condensate and neutralization of its slime in barn: *1*—gas-meter; *2*—tap; *3*—catalase reactor; *4*—cranked vessel; *a*—painted water; *b*—mixture of sample and calcium carbonate ($CaCO_3$); *c*—hydrogen peroxide (H_2O_2) solution

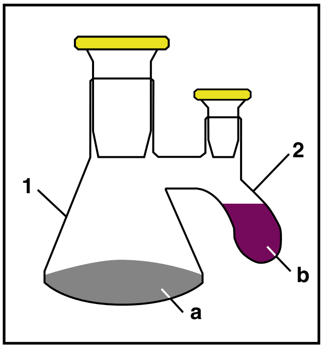


Fig. 2 Device for the dehydrogenase enzyme activity analysis of samples at cleaning of soil polluted by gas condensate and neutralization of its sludge in barn: *1*—the modified Erlenmeyer's flask; *2*—cranked branch of flask; *a*—mixture of sample, calcium carbonate ($CaCO_3$), glucose ($C_6H_{12}O_6$) and 2,3,5-triphenyltetrazolium chloride ($C_{19}H_{15}N_4Cl$) solutions; *b*—saturated alkaline solution of pyrogallol, $C_6H_3(OH)_3$

For the purpose of dehydrogenase activity analysis, 1 g of soil sample, separately from each of above-named variants, and also 0.1 g of finely crushed calcium carbonate ($CaCO_3$), 1 ml of 1% water solutions of glucose ($C_6H_{12}O_6$) and 2,3,5-triphenyltetrazolium chloride ($C_{19}H_{15}N_4Cl$) consistently place in a flask and mixture (a) mixes by roundabouts. By means of a syringe enter saturated alkaline solution of pyrogallol, $C_6H_3(OH)_3$ (b) into a cranked branch for oxygen absorption into device. Further the flask is pressurized by stoppers, using vacuum greasing and put in the thermostat on incubation at 30 °C for 1 day. Biochemical reaction when

Table 1 Enzyme (catalase and dehydrogenase) activity of site soil, polluted of gas condensate, at addition of various biocompost doses

Dose, kg/m^2	Catalase activity, ml O_2/(min·g)	Dehydrogenase activity, mkg 2,3,5-triphenylformazan/(g·day)
Control, 0	1.4	53.4
Biocompost, 4	2.7	305.8
Biocompost, 8	3.4	469.1
Biocompost, 12	3.5	460.1
Biocompost, 16	3.9	472.7

2,3,5-triphenyltetrazolium chloride (colorless substance) accepting the hydrogen mobilized dehydrogenase is began, which is turned in the incubated environment in 2,3,5-triphenylformazan ($C_{19}H_{16}N_4$, substance of red color) (Khaziev 1976):

$$C_{19}H_{15}N_4Cl + H_2 = C_{19}H_{16}N_4 + HCl$$

After incubation completion the extraction of 2,3,5-triphenylformazan, which is formed in studied samples, is made from each flask by means of ethyl alcohol (C_2H_5OH), five times on 4 ml. Further extracts of each sample unite up to the volume of 25 ml and measure optical density by a spectrophotometer at the wavelength of 490 nm and count quantity of a 2,3,5-triphenylformazan according to the calibration schedule made, for example, from 1 to 30 mkg/ml of this substance and express in terms of 2,3,5-triphenylformazan mkg/(g·day).

In general on a basis of these analytical results about the beginning of the process of cleaning and neutralization of samples by biological means judge on the increase of enzyme activities of the recultivated contaminated samples concerning activities of the samples without addition of biological means, and about end of the process of cleaning or neutralization of samples judge on alignment of activities of the recultivated contaminated samples with enzyme activities of the samples of background uncontaminated site soil or itself biological means.

So, at addition of biological means in form of the Piksa biocompost to soil of site polluted by gas condensate (1.8–5.4 g/kg) from a blowing-off candle in the territory of booster compressor station, the catalase activity in 40 days increased by 1.9–2.8 times in comparison with variant without addition of this biocompost (Table 1).

Apparently, with increase of the biocompost dose the effect of cleaning of soil from gas condensate hydrocarbons increases. However the optimum dose of the biocompost can be considered as 8 kg/m^2 since its further increase doesn't lead to so sharp increase by 2.4 times of effect of cleaning as in this case.

Meanwhile under the same conditions the dehydrogenase activity in 40 days increased by 6–9 times in comparison with variant without addition of this biocompost. Apparently, with increase of a dose of the biocompost the effect of cleaning of soil from of gas condensate hydrocarbons also increases. And here also the optimum dose of biocompost can be considered as 8 kg/m^2 since its further increase doesn't lead to such the sharp increase of cleaning effect by 8.8 times as in this case.

As for neutralization of the gas condensate sludge arriving from linear part of the main gas pipelines and from vessels of a high pressure of booster compressor sta-

Table 2 Enzyme (catalase and dehydrogenase) activity of mixture of biocompost with of gas condensate sludge in various ratios for its neutralization in barn

Ratio of biocompost:gas condensate sludge	Catalase activity, ml O_2/(min · g)	Dehydrogenase activity, mkg 2,3,5-triphenylformazan/(g · day)
1:1	3.3	11.0
2:1	5.3	10.8
4:1	5.6	9.5

tion at their purges, it was made in a place of accumulation of substance (in a barn) also by means of the Piksa biocompost. It was established that catalase activity after 40 days of incubation increased with increase of the biocompost : gas condensate sludge ratio (Table 2).

As the optimum ratio of these components it is possible to accept 2:1 as its further increase didn't lead to the similar sharp increase (by 1.6 times) of effect of neutralization as in this case.

Meanwhile under the same conditions it was established that the dehydrogenase activity after 40 days of incubation isn't increased with increase of biocompost:gas condensate sludge ratio (Table 2). As an optimum ratio of these components it is possible to accept also 2:1 as its further increase didn't lead to increase of effect of neutralization as in this case.

4 Conclusions

Thus, the biogeochemical technology of cleaning of soil polluted by gas condensate and neutralization of its sludge consists in analysis of activity of enzymes—catalase and dehydrogenase, which are directly participating in degradation of gas condensate hydrocarbons. In this case about the beginning of process of cleaning of soil from gas condensate and neutralization of its sludge judge on the increase of enzyme activity of the samples with addition of biological means concerning enzyme activity of the samples without addition of biological means, and about the end of process of cleaning and neutralization judge on alignment of enzyme activity of these samples with enzyme activity of the samples of background uncontaminated site soil or itself biological means.

References

Andreev, O. P., Bashkin, V. N., Galiulin, R. V., Arabskiy, A. K., & Makliuk, O. V. (2011). *Solution of geoenvironmental risks problem in the gas industry. Survey information*. Moscow: Gazprom VNIIGAZ Publishing House. 78pp.

Bashkin, V. N., Bukhgalter, E. B., Galiulin, R. V., Konyaev, S. V., Kalinina, I. E., & Galiulina, R. A. (2010a). *Control method for cleaning of soils contaminated by hydrocarbons and neutralization of hydrocarbons sludges by catalase activity analysis*. RU Patent 2387995.

Bashkin, V. N., Bukhgalter, E. B., Galiulin, R. V., Konyaev, S. V., Kalinina, I. E., & Galiulina, R. A. (2010b). *Control method for cleaning of soils contaminated by hydrocarbons and neutralization of hydrocarbons sludges by dehydrogenase activity analysis*. RU Patent 2387996.

Dmitrevskaya, E. S., Krasil'nikova, T. A., & Markova, O. A. (2014). Environmental pollution and radiation situation on the Russian Federation territory in February 2014. *Meteorology and Hydrology, 5*, 102–107.

Khaziev, F. K. (1976). *Enzymatic activity of soils. Methodological textbook*. Moscow: Nauka Publishing House. 180pp.

Koronelly, T. V. (1996). Principles and intensification methods of biological degradation of hydrocarbons in the environment (review). *Applied Biochemistry and Microbiology, 32*(6), 579–585.

Ovanesyants, A. M., Krasil'nikova, T. A., & Ivanov, A. B. (2008). Environmental pollution and radiation situation on the Russian Federation territory in June 2008. *Meteorology and Hydrology, 9*, 102–106.

Sementsov, A. Y. (2006). *«Piksa» Supercompost application for urban soils rehabilitation. Technical recommendations*. Moscow: VNIIA Publishing House. 32pp.

Teranishi, Y., Kawamoto, S., Tanaka, A., Osumi, M., & Fukui, S. (1974). Induction of catalase activity by hydrocarbons in *Candida tropicalis* pK 233. *Agricultural and Biological Chemistry, 38*(6), 1221–1225.

Biogeochemical Control of Peat-Based Recultivation Process of Disturbed Tundra Soils Varying in Granulometric Composition and Full Moisture Capacity

Rauf V. Galiulin, Vladimir N. Bashkin, and Rosa A. Galiulina

Abstract Biogeochemical control of recultivation (fertility restoration) of disturbed tundra soils with various granulometric composition and full moisture capacity includes an assessment of application efficiency of peat in mixture with the disturbed soil. The rational peat:soil ratio is chosen depending on granulometric composition and full moisture capacity of the disturbed soil, i.e. with increasing the physical clay (particles <0.01 mm) content in the soil and water saturation level the amount of peat in mixture is decreasing. At the same time, the dependence of a peat:soil ratio based on granulometric composition is recommended for the territories with the undulating or dissected relief and heterogeneous soil cover, and that based on full moisture capacity, for the territories with flat or weakly dissected relief and monotonous soil cover. Efficiency of using these mixtures of peat with the recultivated disturbed soil is estimated in the conditions of *in vitro* experiment by means of the dehydrogenase enzyme activity analysis. In both cases dehydrogenase activity of this mixture has to be exceeded the enzyme activity of the disturbed soil and accordingly this is resulted in recommending the selected mixture for *in situ* soil recultivation.

Keywords Disturbed soil • Granulometric composition • Full moisture capacity • Peat:soil ratio • Dehydrogenase enzyme activity • Recultivation

R.V. Galiulin (✉) • R.A. Galiulina
Institute of Basic Biological Problems of Russian Academy of Sciences,
Pushchino, Moscow Region 142290, Russian Federation
e-mail: rauf-galiulin@rambler.ru

V.N. Bashkin
Institute of Physicochemical and Biological Problems of Soil Science of Russian Academy of Sciences, Pushchino, Moscow Region 142290, Russian Federation

Institute of Natural Gases and Gas Technologies—Gazprom VNIIGAZ LLC,
Razvilka, Moscow Region 142719, Russian Federation

V.N. Bashkin (ed.), *Biogeochemical Technologies for Managing Pollution in Polar Ecosystems*, Environmental Pollution 26, DOI 10.1007/978-3-319-41805-6_17

1 Introduction

Disturbance of tundra soils, that is deprivation of their vegetable cover and top organogenic layer with an exit of the mineral horizons to a day surface, happens at journey of the equipment connected with geological exploration implementation, drilling of wells and arrangement of crafts on oil and gas production. Meanwhile the tundra soil, as well as a soil in general, has ability to the self-restoration happening by its gradual settling by vegetation, further coming to vegetable litter, development of sod process and accumulation of humus. However in the conditions of severe climate of the tundra, soil self-restoration will demand the long time measured by decades. In this regard it is quite rational to accelerate a restoration of fertility of the disturbed soils by recultivation technologies, and also to estimate its efficiency originally in the conditions of *in vitro* experiment for the purpose of obtaining necessary information for implementation of *in situ* soil recultivation.

Meanwhile it is known the method of visual control of recultivation efficiency of the disturbed tundra soils *in situ* when the soil is covered with a layer (to 5–6 cm) by mixture of peat with pit sand in the ratio 1:4, and supervision over restoration of its fertility is carried out within 15–20 years (Andreev et al. 2003). Application for recultivation not only peat, but also pit sand, and as well the long-term supervision over restoration of fertility of the disturbed soils are among lacks of this method. Other method, also based on visual control of recultivation efficiency of the disturbed soils, includes creation of a fertile layer on the soil, by means of its covering by mixture of peat with sand and other components and implementation of supervision over growth of a vegetable cover in *in situ* conditions within 12–24 months (Sementsov 2006). Essential lacks of this method are use of peat, sand and other components, and also months-long supervision over restoration of fertility of the disturbed soils.

In general, the noted lacks of the considered methods don't allow to use rationally, first of all, peat, in connection with limitation of its stocks on the Far North, and also to estimate in short time-scale the recultivation efficiency of the disturbed soils.

The purpose of this work is developing an approach in the form of biogeochemical control of recultivation of the disturbed tundra soils by means of an assessment of efficiency of using peat in mixture with the disturbed soil taking into account its physic-water properties, that are granulometric composition and full moisture capacity. At the same time the assessment of efficiency of use of peat in mixture with the soil is carried out by means of the dehydrogenase enzyme activity analysis.

2 Conception of Biogeochemical Control of Peat-Based Recultivation Process of Disturbed Tundra Soils Varying in Granulometric Composition and Full Moisture Capacity

The conception of biogeochemical control of peat-based recultivation process of the disturbed soils based on the influence of granulometric composition and full moisture capacity of soils, as well as peat on growth and development of microorganisms, as the main link of biogeochemical cycling, and, therefore, on activity of the microbial produced enzymes, in particular a dehydrogenase. Here the granulometric composition of the soil is understood as the content of various size particles (from 1.0 to <0.001 mm, from sand to silt, accordingly) and the full moisture capacity of the soil is understood as that greatest number of moisture, which contains in soil at full saturation of pores. As for a dehydrogenase, it catalyzes dehydrogenation reactions (hydrogen split off) of the organic substances (carbohydrates, alcohols, organic acids and other compounds) coming with the vegetable remains to the soil and in technological practice this enzyme activity is used as one of the key indicators of process of soil fertility restoration (Galiulin et al. 2013).

It is known that the bulk of soil microorganisms (to 90–99 %) is connected with a solid phase of soil that is explained by ability of soil particles to adsorb microorganisms cells (Mishustin and Emtsev 1978). Interaction of positively charged soil particles with negatively charged cells of microorganisms is the cornerstone of adsorption of microorganisms by the soil. Meanwhile essential distinctions in adsorption ability of various soils in relation to microorganisms have been established, i.e. the heavier granulometric composition of the soil determined by the content of physical clay (particles <0.01 mm), the higher adsorption rate of microorganisms (Minenkov 1928). Accordingly, the maximal absorption of microorganisms is by a fine dust and silt (particles 0.001–0.005 and <0.001 mm) (Mishustin and Emtsev 1978; Kaurichev et al. 1980).

Meanwhile soils of sandy and loamy sand granulometric composition (content of physical clay from 0 % to 20 %) are characterized by the low level of a full moisture capacity, and, in the contrary, soils of heavy loam and clay granulometric composition (content of physical clay from 40 % and >80 %) show the high level of a full moisture capacity (Kaurichev et al. 1982). This is very important that soil at full saturation by moisture of all pores turns practically into the two-phase system, except for insignificant amounts of adsorbed or clamped air, which has remained in the soil (Revut 1972). In this case a practical anaerobiosis favors to anaerobic dehydrogenase activity resulting in splitting off hydrogen from substances like quinones (tetrazolium salts) (Khaziev 1976).

Adequacy of using the dehydrogenase activity for assessing the efficiency of disturbed tundra soil recultivation was earlier proved by carrying out the correlation and regression analysis of *in vitro* experiment data owing to activity of this enzyme and a full moisture capacity of soils (Galiulin et al. 2013). So, calculation of the coefficient of correlation indicating the direction and degree of an associativity in variability of signs was shown the existence of strong essential correlation dependence between dehydrogenase activity and full moisture capacity of soils ($r=0.95$). The corresponding formula of correlation dependence, that is the equation of linear regression allowing to judge as how the productive sign (y) quantitatively changes at change factorial (x) on a unit of measure had the following appearance:

$$y = 7.71 + 0.15x$$

As it was appeared, the higher full moisture capacity corresponds to the higher dehydrogenase activity. The leading role of humidity for dehydrogenase activity of the soil is connected with the fact that moisture defines a normal physiological state of microorganisms and plants as producers of enzymes in the soil, and also supports in a reactionary state enzymes and their substrata (carbohydrates, alcohols, organic acids and other compounds).

As for peat as bioorganic fertilizer, it strengthens enzyme production during recultivation of disturbed tundra soils. The peat being the natural product is characterized by a certain number of various physiological groups of microorganisms (bacteria actinomycetes, fungi and other groups), depending on the location (deposit or pile), depth of excavation, rate of degradation and pH values (Emel'yanova and Kramarenko 2004).

Therefore, in the disturbed tundra soils with peat applying, weighting granulometric composition and increasing full moisture capacity dehydrogenase activity *per se* has to increase that allows to use this indicator for assessing recultivation efficiency of soils by means of the enzyme activity analysis.

3 Step by Step Control of Peat-Based Recultivation Process of Disturbed Tundra Soils Varying in Granulometric Composition and Full Moisture Capacity

The first stage of recultivation of the disturbed tundra soils is the analysis of granulometric composition and full moisture capacity of the disturbed soils. So, the granulometric composition analysis of soils is carried out by the methods described in numerous works (Kaurichev et al. 1980; Radojevic and Bashkin 2006; Estefan et al. 2013). The essence of this method consists in suspension preparation by grinding of a soil sample with the dispersing substance (sodium pyrophosphate, $Na_4P_2O_7$, sodium hexametaphosphate, $Na_6P_6O_{18}$—Grakham's salt et al.) in analysis of the content of various soil fractions by pipette-method, that is by pipette sampling of suspension samples from various depths of measured cylinders through certain time periods. The number of the mentioned particle fractions is sized from 1.0 to <0.001 mm, from sand to silt. Further suspension samples are evaporated, dried up, weighed and the corresponding calculations are making for calculating the content of various fractions by a special method.

After definition of granulometric composition of the studied soil the necessary ratio of a peat:soil mixture for recultivation purpose is chosen from Table 1.

In this table as a starting settlement of peat:soil mixture, the ratio peat:friable sand (1:4) was recommended to be used (Andreev et al. 2003).

Apparently from the table, here are presented the whole nine peat:soil ratios corresponding to nine kinds of the soils differing on granulometric composition. Precisely such detailed gradation of soils on their granulometric composition, required for the choice of the corresponding peat:soil ratio, must to be as the base of soil recultivation on territories with undulating or dissected relief and heterogeneous soil cover.

Table 1 Peat:soil ratio in dependence from granulometric composition of disturbed tundra soil for recultivation

Soil classification on granulometric composition	Content of physical clay (particles <0.01 mm), %	Peat:soil ratio
Friable sand	0–5	1:4
Consolidated sand	5–10	1:4
Loamy sand	10–20	1:4 ÷ 1:5
Light loam	20–30	1:5 ÷ 1:6
Middle loam	30–40	1:6 ÷ 1:7
Heavy loam	40–50	1:7 ÷ 1:8
Light clay	50–65	1:8 ÷ 1:11
Middle clay	65–80	1:11 ÷ 1:20
Heavy clay	>80	1:20

Table 2 Peat:soil ratio in dependence from full moisture capacity level of recultivated disturbed tundra soils

Soil full moisture capacity level	Full moisture capacity, %	Peat:soil ratio
Low level	40–70	1:4–1:6
High level	70–100	1:7–1:9

As for the analysis of a full moisture capacity of the soil, it is quite simple performed by (Revut 1972; Estefan et al. 2013). So, for example, the dry sample of the soil (mass of 10–20 g) is placed in a glass tube (height of 10 cm and with an internal diameter of 2–3 cm), which lower end is tied up by a gauze layer with filter paper, and established in a vessel with water so that water level coincided with the top edge of the soil.

This tube is left in water for 12–14 h before full saturation of the soil by water and the full moisture capacity of the soil (FMCS) is counted (in %) on a formula:

$$\mathrm{FMCS} = \left(\left(a - b\right) / b\right) \cdot 100\ \%,$$

where: a is soil weight with water after saturation (g), b is the weight of the dry soil (g).

After defining a full moisture capacity of the soil the necessary peat:soil ratio for recultivation is chosen from Table 2.

In this table as a starting settlement ratio, also the peat : pit sand ratio, equal 1:4, recommended in (Andreev et al. 2003) is used, where pit sand is characterized by the low level of a full moisture capacity. Apparently in Table 2 only two ranges of peat:soil ratios are presented, corresponding two levels of sub-kinds of the soils differing on a full moisture capacity. Precisely such a small number of gradation of soils on a full moisture capacity, required for the choice of the corresponding peat:soil ratio, must to be as the base of soil recultivation on the territories with a flat or weakly dissected relief and a monotonous soil cover.

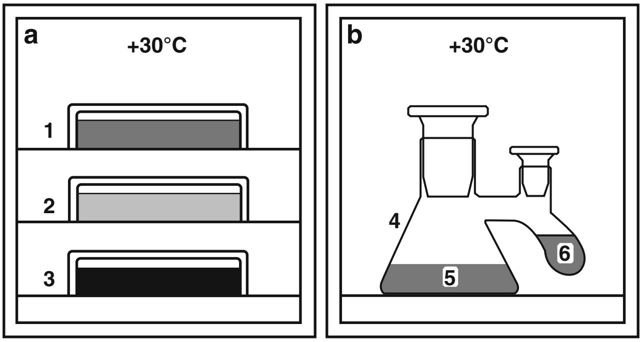


Fig. 1 Equipment and devices for confirmation of recultivation efficiency of disturbed soils: (**a**, **b**)—thermostats; *1*, *2* and *3*—the Petri's dishes; *4*—the modified Erlenmeyer's flask

At the second stage for confirmation of a peat:soil mixture efficiency for recultivation of the disturbed soils we carry out the comparative analysis of the dehydrogenase activity of a peat:soil mixture with the enzyme activity of the disturbed soil and the peat in controlled hydrothermic conditions by the method protected by the patent of the Russian Federation (Arno et al. 2013). For this purpose samples of various variants—the peat:soil mixture (1), the disturbed soil (2) and the peat (3), everyone weight on 50 g,—place in Petri's dishes and humidify to 70 % of a full moisture capacity is supported (Fig. 1). The Petri's dishes with samples place in the thermostat (a) for incubation at 30 °C. In each 5–10 days samples are selecting in sixfold frequency, in quantities sufficient for dehydrogenase activity analysis, after their moisture reduction to an air-dry state. Enzyme activity is determined by the device in form of the modified Erlenmeyer's flask (4) with a cranked branch of flask.

For the purpose of the dehydrogenase activity analysis, 1 g of sample, separately from each above-named variants, and also 0.1 g of thin the crushed calcium carbonate ($CaCO_3$), 1 ml of 1 % water solutions of glucose ($C_6H_{12}O_6$) and 2,3,5-triphenylt etrazoliumchloride ($C_{19}H_{15}N_4Cl$) consistently place in the modified Erlenmeyer's flask (4) and mixture (5) is mixing by roundabouts. In the cranked branch of flask by means of a syringe one enters saturated alkaline solution of pyrogallol, $C_6H_3(OH)_3$ (6) for absorption of oxygen (O_2) in the flask. Further the flask is pressurized by stoppers with use of vacuum greasing and put in the thermostat (b) on incubation at 30 °C for 1 day. It starts biochemical reaction when 2,3,5-triphenyltetrazoliumchlo ride (colorless substance) accepting the hydrogen mobilized dehydrogenase, turns in the incubated environment in 2,3,5-triphenylformazan ($C_{19}H_{16}N_4$, substance of red color) (Khaziev 1976):

$$C_{19}H_{15}N_4Cl + H_2 = C_{19}H_{16}N_4 + HCl$$

After completion of incubation of samples one makes the extraction of a 2,3,5-triphenylformazan, which is formed in them, from each flask by means of ethyl alcohol (C_2H_5OH), five times on 4 ml. Then extracts of each sample one unites up to the volume of 25 ml and measures the optical density by the spectrophotometer at wavelength λ = 490 nm and counts the quantity of a 2,3,5-triphenylformazan according to the calibration schedule made, for example, from 1 to 30 mkg/ml of this substance and express in 2,3,5-triphenylformazan mkg/(g · day) or percentage of enzyme activity in the peat. At calculation of enzyme activity in various samples one should consider their humidity.

About efficiency of use of this peat:soil mixture for disturbed soil recultivation we judge on an increase of the dehydrogenase enzyme activity not less than for 20 % concerning sample of the disturbed soil that allows recommending this mixture for the recultivation. So, in the conditions of *in vitro* experiment we are estimated the possibility of recultivation of two disturbed tundra soils of consolidated sand granulometric composition (content of physical clay, i.e. particles <0.01 mm, is 5–10 %) from the Taz peninsula (68°09′N, 76°02′E) located beyond the Arctic Circle (±66○33′44″), by the corresponding mixtures of a peat:soil in the ratio 1:4 (Table 1). Apparently from Fig. 2 for 20 days of incubation the enzyme activity increased on average for 20 and 46 % (2 and 4) in comparison with variants with samples of the disturbed soils (1 and 3).

The second soil (4) appeared the closest to activity of the peat. Results of the *in vitro* experiment allow us to recommend these mixtures of a peat:soil (1:4) for recultivation of the disturbed tundra soils of consolidated sand granulometric composition by their covering in advance prepared mixture a layer to 5–6 cm.

In similar conditions the possibility of recultivation of three disturbed tundra soils with the low level of a full moisture capacity, FMC (40–70 % of FMC) from the same territory, the corresponding mixtures of peat with recultivated soils in 1:4, 1:5 and 1:6 ratios were estimated. Apparently from Fig. 3, dehydrogenase activity of the disturbed soils (1, 3 and 5) in 10 days of incubation was respectively 8, 7 and 9 mkg of a 2,3,5-triphenylformazan/(g · day), and peat mixtures with the disturbed soils (2, 4 and 6)—29, 27 and 29 mkg of a 2,3,5-triphenylformazan/(g · day), i.e. the enzyme activity increased in 3.6, 3.9 and 3.2 times that was almost identical to all mixtures.

Results of the *in vitro* experiment allowed us to consider as the optimum mixture of peat with the disturbed soils in the ratio 1:5 and to recommend this mixture for recultivating disturbed tundra soils by their covering in advance prepared mixture of the 5–6 cm layer.

4 Conclusions

Thus, biogeochemical control of recultivation (fertility restoration) of the disturbed tundra soils with various granulometric composition and full moisture capacity includes an assessment of application efficiency of peat in mixture with the disturbed soil. The rational peat:soil ratio is chosen depending on granulometric composition and full moisture capacity of the disturbed soil, i.e. with increasing the physical clay (particles <0.01 mm) content in the soil and water saturation level the amount of peat

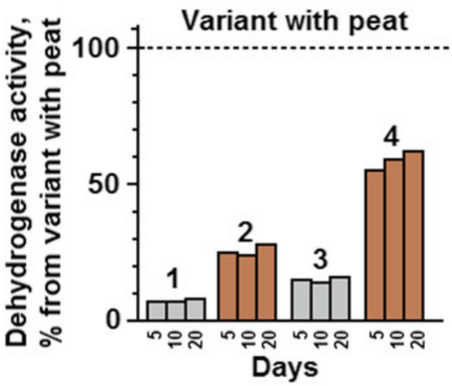


Fig. 2 Dehydrogenase activity of disturbed soil samples without peat introduction (*1* and *3*) and disturbed soils with peat addition (*2* and *4*)

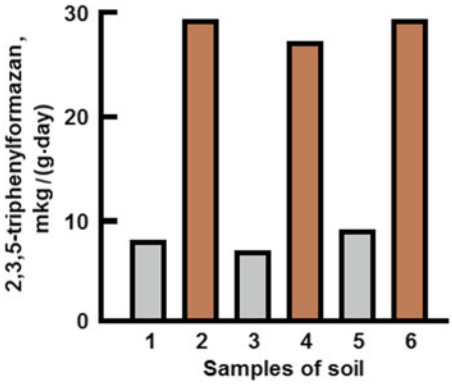


Fig. 3 Dehydrogenase activity of disturbed tundra soils (*1*, *3* and *5*) and mixtures of peat with recultivated disturbed soils (*2*, *4* and *6*) in various ratios (1:4, 1:5 and 1:6)

in mixture is decreasing. At the same time, the dependence of a peat:soil ratio based on granulometric composition is recommended for the territories with the undulating or dissected relief and heterogeneous soil cover, and that based on full moisture capacity, for the territories with flat or weakly dissected relief and monotonous soil cover. Efficiency of using these mixtures of peat with the recultivated disturbed soil is estimated in the conditions of *in vitro* experiment by means of the dehydrogenase enzyme activity analysis. In both cases dehydrogenase activity of this mixture has to be exceeded the enzyme activity of the disturbed soil and accordingly this is resulted in recommending the selected mixture for *in situ* soil recultivation.

References

Andreev, O. P., Stavkin, G. P., Levinzon, I. L., Perepielkin, I. B., & Lobastova, S. A. (2003). Protection and restoration of lands and landscapes of Far North at gas production. *Ecology and the Industry of Russia, 6*, 4–9.

Arno, O. B., Arabskiy, A. K., Bashkin, V. N., Galiulin, R. V., Galiulina, R. A., Makliuk, O. V., et al. (2013). *Control method of recultivation effectiveness of disturbed tundra soils of various granulometric composition by dehydrogenase activity analysis.* RU Patent 2491137.

Emel'yanova, T. Y. A., & Kramarenko, V. V. (2004). Justification of a technique of studying of deformation properties of peat taking into account change of extent of its degradation. *News of Tomsk Polytechnic University, 307*(5), 54–57.

Estefan, G., Sommer, R., & Ryan, J. (2013). *Methods of soil, plant, and water analysis. A manual for the West Asia and North Africa region* (3rd ed.). Beirut: ICARDA Publishing. 243pp.

Galiulin, R. V., Bashkin, V. N., Galiulina, R. A., Priputina, I. V., & Arabskiy, A. K. (2013). Recultivation of disturbed tundra soils of the Tazovsky peninsula by means peat: Assessment of efficiency by enzyme activity analysis. *Agrochemistry, 4*, 76–80.

Kaurichev, I. S., Aleksandrova, L. N., Grechin, I. P., Panov, N. P., Poddubny, N. N., & Rozov, N. N. (1982). *Soil science* (3rd ed.). Moscow: Kolos Publishing House. 496pp.

Kaurichev, I. S., Panov, N. P., Stratonovich, M. V., Grechin, I. P., Savich, V. I., & Ganjara, N. F. (1980). *Practicum on soil science* (3rd ed.). Moscow: Kolos Publishing House. 272pp.

Khaziev, F. K. H. (1976). *Enzymatic activity of soils. Methodological textbook*. Moscow: Nauka Publishing House. 180pp.

Minenkov, A. R. (1928). Adsorption bacteria by different soil type. *Diary of All-Union Congress of Botanists*. Leningrad (pp. 206–207).

Mishustin, E. N., & Emtsev, V. T. (1978). *Microbiology* (2nd ed.). Moscow: Kolos Publishing House. 351pp.

Radojevic, M., & Bashkin, V. N. (2006). *Practical environmental analysis* (2nd ed.). Cambridge: SCP Publishing. 457pp.

Revut, I. B. (1972). *Physics of soils* (2nd ed.). Leningrad: Kolos Publishing House. 368pp.

Sementsov, A. I. (2006). *«Piksa» Supercompost use for urban soils rehabilitation. Methodical recommendations*. Moscow: VNIIA Publishing House. 32pp.

Biogeochemical Technology for Disturbed Tundra Soils Recultivation by Peat and Potassium Humate Application

Vladimir N. Bashkin, Rauf V. Galiulin, Andrey O. Alekseev, Rosa A. Galiulina, and Anastasia N. Maltseva

Abstract The biogeochemical technology of recultivation of disturbed tundra soils includes the joint application of local peat and its potassium humate from the Taz peninsula (the Yamalo-Nenets Autonomous Okrug). At the same time the potassium humate is produced from humic acids of local peat by consecutive decalcifying, extraction, sedimentation and clarification. Efficiency of application of peat and potassium humate to the disturbed soils in doses depending from their granulometric composition is estimated on a basis of biomass of grown grass-cereals plants. The given technology is forwarded to increasing the efficiency of recultivation of the disturbed soils.

Keywords Disturbed tundra soils • Local peat • Potassium humate • Soil granulometric composition • Grassy-cereals plants • Recultivation

1 Introduction

So-called disturbance of tundra soils in oil-gas industry is connected with destruction of a fertile layer happens in particular, on routes of the roads and pipelines laid at construction of wells. Meanwhile, soil as the bioinert natural body has an ability to the self-restoration by gradual processes including vegetation settling, biomass

V.N. Bashkin (✉)
Institute of Physicochemical and Biological Problems of Soil Science of Russian Academy of Sciences, Pushchino, Moscow Region 142290, Russian Federation
e-mail: Bashkin@issp.serpukhov.su

Institute of Natural Gases and Gas Technologies—Gazprom VNIIGAZ LLC, Razvilka, Moscow Region 142719, Russian Federation

R.V. Galiulin • R.A. Galiulina
Institute of Basic Biological Problems of Russian Academy of Sciences, Pushchino, Moscow Region 142290, Russian Federation

A.O. Alekseev • A.N. Maltseva
Institute of Physicochemical and Biological Problems of Soil Science of Russian Academy of Sciences, Pushchino, Moscow Region 142290, Russian Federation

V.N. Bashkin (ed.), *Biogeochemical Technologies for Managing Pollution in Polar Ecosystems*, Environmental Pollution 26, DOI 10.1007/978-3-319-41805-6_18

formation with annual litter and humus accumulation. Depending on climate zone this natural recultivation process will last from a few years up to a few decades and the latter is typical for severe climate of the tundra. Accordingly, this natural process must be intensified. From technological point of view this will be rational to estimate the recultivation efficiency originally in the conditions of *in vitro* experiment for obtaining necessary technical and operational parameters and subsequent implementation of these *in situ* recultivation of soils (Galiulin et al. 2013). To number of similar methods of soil recultivation one should refer to application of organic fertilizers, for example, the peat and its humates (i.e. the humic acid salts). It is known that peat consists both from not completely degraded plant remains and from products of their degradation in the form of humus including, in particular, the humic acids, which are characterized by the high content of carbon and also all nutritious elements, necessary for plants. From the most important nutrients, such as nitrogen, phosphorus and potassium, the nitrogen content in various peats is typically maximal, up to 3.5 %. Besides peat has a certain pool of various physiological groups of the microorganisms (bacteria, actinomycetes, fungi and other groups) participating in degradation of peat organic substance that makes nutrients available for plants (Emel'yanova and Kramarenko 2004). Meanwhile the dark color of peat promotes absorption of heat and fast warming up of the soil that is especially important in the conditions of the Far North. As for a humate, it positively influences on growth and development of plants, intensifying exchange processes and possessing membranetrope action, increases resistance of plants to adverse effects of external environment including to low temperatures (Galaktionova 1998).

The purpose of this work is development of the biogeochemical technology of recultivation of the disturbed tundra soils by means of joint application of peat and relevant potassium humate extracted from the given peat. At the same time local peat of the Taz peninsula (the Yamalo-Nenets Autonomous Area) located beyond the North Polar Circle is used. The efficiency of the peat and potassium humate application soil recultivation is estimated on the basis of biomass grass-cereals plants.

For realization of this goal it was necessary to develop different technological steps, namely, to estimate the known methods of producing humates from peat and offer the innovative one, and also critically estimate the existing methods of recultivation of the disturbed soils with application of peat, humates and other components. Furthermore, from methodological viewpoint, we need the concept of recultivation of disturbed tundra soils by means of joint application of local peat and potassium humate and, at last, to describe the relevant biogeochemical technology.

2 The Existing Methods of Producing Humates from Peat

In literature, in particular, there are methods of receiving uterine solution of a sodium humate from peat, by its direct processing by sodium hydroxide (NaOH), without carry out of the procedure of decalcifying, multiple extraction and clarification that however doesn't guarantee chemical purity and stability of the received preparation of this substance (Razumov and Gusev 2000; Razumov 2001; Komissarov et al. 2004). It is also known the method of receiving the potassium humate by direct potassium hydroxide (KOH) processing (Apkaneev et al. 2006). It should be noted that the sodium humate unlike a humate of potassium isn't rather effective preparation for restoration of soil fertility as it leads to reducing plant uptake of such important nutritious element as potassium. Meanwhile for normalization of physiological processes in plants (for example, formations of carbohydrates and vitamins and activation of various enzymes), and also increasing their frost resistance in severe climatic conditions of the Far North, namely the potassium is required.

Thus, the humates produced from peat on a basis of NaOH extraction procedures can't be used for recultivation of the disturbed tundra soils: first, the given technological procedures do not guarantee the required degree of chemical purity and stability of the received preparations, and secondly, sodium itself has negative physiological effects on soil and plants. Potassium humate is more appropriate.

Meanwhile for producing chemically pure and stable potassium humate the relevant technology was carried out, including extraction of humic acids from peat and their cleaning with receiving chemically pure substances and subsequent assessing molecular structures of these acids (Chumak and Sartakov 2014).

These allow developing the following.

3 Step by Step Receiving of Potassium Humate from Peat

The technology of receiving potassium humate from peat includes the following stages:

1. decalcifying of peat by 0.1 N solution of sulfuric acid (H_2SO_4) at the ratio 1:20. Then the received suspension is left for 1 days and after settling the solution from a solid phase is separated by decantation from a deposit;
2. carrying out 4–5 multiple extractions (duration up to 20 h) of humic acids from the received deposit by 0.1 N sodium hydroxide (NaOH) at the ratio 1:15. Then the solid phase is separated from alkaline solution by centrifugation;
3. sedimentation (within 1 days) of humic acids from the received alkaline solution by 10 % solution of hydrochloric acid (HCl) at the ratio 50:1 with the subsequent deposit separation by centrifugation;
4. clarification of the received deposit of humic acids by dissolution in 0.5–1.0 l of 0.1 N of sodium hydroxide (NaOH) solution, and also addition of sodium sulfate (Na_2SO_4) for coagulation of mineral particles and the subsequent centrifugation of alkaline solution. The humic acids precipitate by addition 0.1 N of solution of hydrochloric acid (HCl) before establishment of pH up to 1–2 units. Then the deposit of humic acids is repeatedly washed out by the distilled water before establishing pH up to 6 and the deposit dried up in the thermostat at 50 °C;

5. preparation of the uterine 2.5 % of solution of a potassium humate by means of addition of the distilled water and 0.1 N of potassium hydroxide (KOH) solution with the subsequent finishing pH 7 of required solution. From the uterine solution the 0.125 % water solution of a potassium humate for recultivation of the disturbed soils is prepared.

4 The Existing Methods for Recultivation of Disturbed Soils with Applying Peat, Potassium Humate and Other Components

It is known the method of recultivation of the soil including application of a so-called soil modificator of prolonged action in the form of the multicomponent composition consisting of imported peat, a potassium humate and additionally the compost received by mixing cattle manure, bird's dung and peat (Sukhanov et al. 2009). Lacks of this method is application of the soil modificator of compound composition for recultivation of soils without indication as how to assess its doses and efficiency.

In other method, the recultivation of the disturbed soils is carried out by their covering by biocompost of complex composition received from imported peat, manure of cattle, mineral, organic and organo-mineral fertilizers (Sementsov 2006). The efficiency of recultivation of soils is estimated by supervision within 12–24 months over growth of grass vegetation. The essential lacks of this method are application of complex composition compost and long supervision over creation of a fertile layer on the disturbed soils.

In general, the noted lacks of the above-exampled methods don't allow us to use them for recultivation of disturbed tundra soils.

5 Conception of Recultivation of Disturbed Tundra Soils by Means Local Peat and Potassium Humate Application

The essence of the concept of recultivation of the disturbed tundra soils consists in joint application of local peat and produced from this peat potassium humate and also assessment of recultivation efficiency by cultivation of grassy-cereals plants originally in the conditions of *in vitro* experiment for the purpose of obtaining necessary technical information for further implementation of *in situ* recultivation of soils.

Meanwhile the expediency of application of the local peat and potassium humate produced from this peat for the disturbed tundra soil recultivation is based on identification of zonal signs of the given peat, by the comparative analysis of peat humate chemical composition with the same from other region. This analysis

Table 1 Comparative assessment of different carbon kind content (%) in structural fragments of humic acids of the peat from the Taz peninsula and the Middle Ob river basin

Carbon kind	Taz peninsula	Middle Ob river basin (Sartakov 2008)
Aliphatic	37.9–54.0	42.2–47.1
Aromatic	14.1–23.2	36.3–42.1
Polysaccharide	23.1–26.8	5.5–13.3
Carboxyl	7.9–10.1	4.7–8.8

assumes, in particular, determination of relative content of atoms of aliphatic, aromatic, polysaccharide and carboxyl carbon in structural fragments of humic acids by method of nuclear-magnetic-resonant ^{13}C-spectroscopy (Kalabin et al. 2000).

So, a comparative assessment of content of the called kinds of carbon in the peat humate from the Taz peninsula with similar indicators of the peat humate of the Middle Ob river basin (the Khanty-Mansiysk Autonomous Okrug, Sartakov 2008) have allowed us to reveal the certain statistically significant distinctions in the content of the relevant substances, Table 1. These distinctions are noted, first of all, in the prevailing content of aliphatic carbon, in comparison with aromatic carbon in the peat humate from the Taz peninsula as the most significant indicator of structure of a carbon skeleton of humic acids and formulated as the first zonal sign. Besides, the received ratio between two kinds of carbon demonstrates the disturbed hydrophilic-hydrophobic balance as aliphatic fragments of humic acids are carriers of hydrophilic properties unlike hydrophobic aromatic fragments (Vozbutskaya 1968). While almost identical level of content of aliphatic and aromatic carbon in the peat humate from the Middle Ob river basin proves existence of hydrophilic-hydrophobic balance.

Essential distinctions are noted in the bigger content of polysaccharide carbon in the peat humate from the Taz peninsula, than in the peat from the Middle Ob river basin that indicates a significant role of polysaccharides in formation of humic acids in the peat, and on existence of the second zonal sign.

In general, the revealed zonal signs of humic acids of the peat from the Taz peninsula confirm "compatibility" with a soil-vegetable cover and serve the powerful basis for application of local peat as organic fertilizer for recultivation of the disturbed tundra soils. So-called "compatibility" of local peat with a soil-vegetable cover of the Taz peninsula is caused, in particular, by general distribution of such perennial plant as sphagnum moss (*Sphagnum*) on undisturbed mineral and on organogenic (peat) soils of the peninsula. The sphagnum moss accumulating the mineral substances arriving with rainfall, and degrading upon completion of life cycle, gives them to the spreading soil together with the biomass and is an important source of the peat formation.

As for use, in our case, of grassy-cereals plants for recultivation of the disturbed tundra soils, that it is connected with the fact that the initial stage of self-restoration of fertility of soils is characterized by settling of specified association of plants (Galiulin et al. 2013). The final period of regeneration of a vegetable cover happens on the disturbed soils by gradual replacement of different types of grassy-cereal association of plants, in particular mosses and lichens, native for a tundra zone.

Table 2 Doses of peat and 0,125 % water solution of potassium humate in dependence on granulometric composition of disturbed tundra soil

Soil classification on granulometric composition	Content of physical clay (<0.01 mm particles), %	Dose of peat, kg/m^2	Dose of 0.125 % water solution of potassium humate, l/m^2
Friable sand	0–5	2.0	2.4
Consolidated sand	5–10	1.8	2.0
Loamy sand	10–20	1.6	1.6
Light loam	20–30	1.4	1.2

6 Step by Step Recultivation of Disturbed Tundra Soils by Means Local Peat and Its Potassium Humate Application

The technology includes carrying out recultivation of the disturbed tundra soils by means of consecutive application of local peat and water solution of the potassium humate produced from this peat, and also crops and cultivation of mixture of grassy-cereals plants in the conditions of *in vitro* experiment.

1. At the first stage we choose doses of peat and 0.125 % of water solution of a potassium humate depending on granulometric composition of the disturbed soil (Table 2).

Here under the granulometric composition of the soil is understood the content of particles of various size, from sand to silt, i.e. the particles by the sizes from 1.0 to <0.001 mm (Kaurichev et al. 1980). In present case, the peat from peat mining crushed and dried by periodic loosening to a condition of friability is applied for recultivation.

2. At the second stage, in plastic vessels (capacity of 0.25 l) we incubate (in six-fold frequency) 100 g samples of the disturbed tundra soil with previously brought peat and samples of the disturbed tundra soil also with previously brought peat and 0.125 % water solution of the potassium humate and with seeding and cultivation of grassy-cereals mixture in both variants. Incubation of the samples is carried out within 30 days at day lighting in controlled hydrothermic conditions, i.e. soil humidity of 70 % of a full moisture capacity and with imitation of the average monthly summer temperature typical of the study region. Here under a full moisture capacity of the soil is understood that greatest number of moisture, which in the soil contains at full saturation of all its pores (Kaurichev et al. 1980).

Among plant mixture can be a crested dog's-tall (*Cynosurus cristatus*), smooth meadow-grass (*Poa pratensis*), red fescue (*Festuca rubra*), creeping bent grass (*Agrostis alba*) and English ryegrass (*Lolium perenne*), for the purpose of receiving

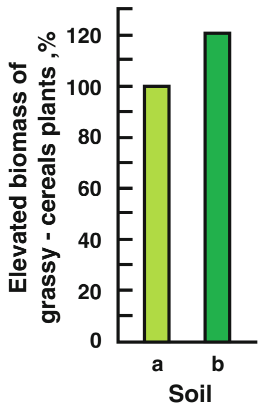


Fig. 1 Biomass of grassy-cereals plants growing up on soil with application of local peat (**a**) and soil with joint application of local peat and 0.125 % water solution of potassium humate (**b**)

the dense herbage and the dense turf. The dose of seeds undertakes at the rate of 30 g/m^2.

3. At the third stage, after mowing we define the biomass of grassy-cereals plants in various variants of experiment. About efficiency of recultivation of the disturbed tundra soils we judge by an increase (in %) the biomass of grassy-cereals plants on the soil with joint application of peat and potassium humate relatively the same at the soil with application only of peat.

So, in the conditions of *in vitro* experiment we estimated a possibility of recultivation of the disturbed tundra soil of the consolidated sand granulometric composition (content of physical clay, i.e. particles <0.01 mm, is 5–10 %) from the Taz peninsula, by peat application (1.8 kg/m^2) and 0.125 % water solution of potassium humate (2.0 l/m^2), by Table 2. Apparently from Fig. 1 the biomass of grassy-cereals plants in the disturbed soil with joint application of peat and 0.125 % water solution of a potassium humate was 21 % more, than in the soil with application only of peat.

7 Conclusions

Thus, the biogeochemical technology of recultivation of the disturbed tundra soils includes joint application of local peat and the potassium humate produced from this peat. At the same time the potassium humate is produced from the peat humic acids by consecutive decalcifying, extraction, sedimentation and clarification. Efficiency of joint application of peat and potassium humate in the disturbed soils, in doses depending on soil granulometric composition, is estimated on elevated biomass of the grown-up of grass-cereals plants. This technology allows *in practice* to increase recultivation efficiency of the disturbed tundra soils.

References

Apkaneev, A. V., Degtyariev, V. V., & Chumakov, A. N. (2006). *Method of receiving of water-soluble humate*. RU Patent 2286970.

Chumak, V. A., & Sartakov, M. P. (2014). *Experience of studying of conditions of big crops receiving on the far north*. Khanty-Mansiysk: AU «Tekhnopark vysokikh tekhnologiy» Publishing House. 514pp.

Emel'yanova, T. Y. A., & Kramarenko, V. V. (2004). Justification of a technique of studying of deformation properties of peat taking into account change of extent of its degradation. *News of Tomsk Polytechnic University, 307*(5), 54–57.

Galaktionova, A. A. (1998). Ecological aspects of use of peat-humic fertilizers. *Agrarian Science, 6*, 13–15.

Galiulin, R. V., Bashkin, V. N., Galiulina, R. A., Priputina, I. V., & Arabskiy, A. K. (2013). Recultivation of disturbed tundra soils of the Taz peninsula by means peat: assessment of effectiveness by enzyme activity analysis. *Agrochemistry, 4*, 76–80.

Kalabin, G. A., Kanitskaya, L. V., & Kushnarev, D. F. (2000). *Quantitative spectroscopy of a nuclear-magnetic-resonance of natural organic raw materials and products of its processing*. Moscow: Khimiya Publishing House. 408pp.

Kaurichev, I. S., Panov, N. P., & Stratonovich, M. V. (1980b). *Practicum on soil science* (3rd ed.). Moscow: Kolos Publishing House. 272pp.

Komissarov, I. D., Grekhova, I. V., Mikheev, M. Iu., Gordeeva, A. I., Strel'tsova, I. N., & Ustupalova, V. A. (2004). *Method of receiving of humic biostimulator*. RU Patent 2228921.

Razumov, V. I. (2001). *Method of receiving of sodium humate uterine solution*. RU Patent 2177021.

Razumov, V. I., & Gusev, K. K. (2000). *Method of receiving of sodium humate*. RU Patent 2150484.

Sartakov, M. P. (2008). Spectroscopy of a nuclear-magnetic-resonance ^{13}C of humic acids of peat of the Middle Ob river basin. *Chemistry of Vegetable Raw Materials, 3*, 135–139.

Sementsov, A. I. U. (2006). *«Piksa» Supercompost use for urban soils rehabilitation. Methodical recommendations* (p. 32). Moscow: VNIIA Publishing House.

Sukhanov, V. M., Moshchenskaya, N. V., Dolzhich, A. R., & Retuev, A. V. (2009). *Soilmodificator of prolonged action and method of its receiving*. RU Patent 2345976.

Vozbutskaya, A. E. (1968). *Chemistry of soil* (3rd ed.). Moscow: Vyshaya Shkola Publishing House. 463pp.