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LAND USE CHANGES IN THE TRANS-BOUNDARY AMUR RIVER BASIN IN THE 20TH CENTURY

ABSTRACT: All distinctions in the economic and nature protection policy of the neighboring states are well reflected and shown within trans-boundary river basins. The parts of trans-boundary geosystem of one country can experience an essential negative influence from rash decisions in the field of nature use and nature protection policy of the neighboring state. The Amur River Basin covers the territories of Russia, the Peoples Republic of China, Mongolia and Democratic People's Republic of Korea and occupies more than 2 million km². The most intensive development of the basin territory has started since the middle of the 19th century. We compiled two maps of land use in the Amur River basin in the 1930–1940s and in the early 21st century. Results showed that, negative dynamics is marked for forest lands, meadows, wetlands and mountain tundra. The basic features in the change of land use within national parts of the basin in Russia, China and Mongolia are analyzed. The comparative analysis of land use peculiarities of the countries for the last 70 years has been done.

KEY WORDS: land use and land cover changes, topographic maps, remote sensing, the Amur River Basin

INTRODUCTION

Any country, as a rule, aspires not only to strictly define and support its own sovereignty by means of its frontiers, but also to develop certain cooperation with other countries, especially with its neighbors. In this process, frontier territories can play a pioneer role. In case the aspiration to develop various means of cooperation, including economic and humanitarian, with neighboring countries is mutual, there begins an active interaction of adjacent frontier territories. Infrastructural links of frontier areas are formed and developed, specifically, transport transitions, communication lines and power grids, and some links of market infrastructure. As a result, a trans-boundary territory is formed from closely and steadily co-operating frontier territories. This trans-boundary territory often has a common uniform natural and geographical basis that strengthens coherence within trans-boundary territories, and simultaneously demands for the development of shared approaches to nature management to working out of joint programs of development.

Complete watersheds of large rivers, lakes, sea basins are integral geosystems of the

highest rank. If the integral geosystem simultaneously enters two or more countries, it would be considered and assessed as a uniform geosystem at the top level. Within trans-boundary geosystems which are components of uniform river watersheds, all distinctions in the economic and nature conservation policies of the neighboring countries are appreciably shown. The negative impacts on the environment of pollution from various wastes of economic activities, and the use of natural resources, such as water, forest, ground and mineral resources, within one country can be manifested in another country. Catastrophic natural phenomena, such as floods, can also be manifested within basin geosystems as a whole. The international experience of development of trans-boundary territories and our studies show that, at first, sustainable nature management can be realized in different territorial patterns. Second, under conditions of inefficient nature management, one frontier territory can cause a negative impact on the nature management of a neighboring frontier territory as a rule. Therefore, comparative assessments of nature management patterns which are formed on the frontier territories of neighboring countries are necessary. At the same time, observing the long-term land use/cover changes in a certain region of the world is one of the more interesting and important tasks of LUCC (Land Use/Cover Change) studies.

The Amur River Basin is a good example of a trans-boundary trans-regional basin-type geographical structure. Its total area exceeds 2 million km². About 50% of its territory belongs to Russia, 42% to China, and 8% to Mongolia. Previous studies on the basin's territories of these three countries were significantly different. Investigations in the southern part of the Russian Far East in the end of the 19th–20th century were mostly oriented on the study of natural conditions – vegetation, soils, and geomorphology, among others. The works of Anuchin [1896] were the first, and they considered a complex of the

natural features, population, and economy of Manchuria. A great volume of research works that are both scientific and applied in nature has been produced by the Amur Expedition, a research body organized at the beginning of the last century [Kryukov, 1911; Korotkii, 1912] to study opportunities for economic development in Amuro-Ussuriiski krai, further resettlement of peasants, and development of trade and industry. During the second part of the 20th century, works devoted to the economic and geographical characteristics of Manchuria were published [Anuchin, 1948; Glushakov, 1948].

An essential contribution to the accumulation of extensive material about differentiation in natural environments in the Amur River watershed has been made by the Russian-Chinese Joint Amur Expedition under the Council on Industrial Forces Organization of the USSR Academy of Science and by the Heilongjiang Expedition of the People's Republic of China. These studies were carried out as surveys in the 1956–1962 [Nikolskaya and Chichagov, 1957]. The results of these surveys became the basis for fulfilling a series of thematic works, in which the natural environment of the Amur River watershed was considered not only within separate countries but also as an integral geographical formation. These works included studies about the soil and geographical zoning of the Amur River by Liverovskii and Rubtsova [1962], a vegetation map of the Amur River watershed [Sochava, 1969], and a number of others. Modern interest in studies on the trans-boundary watershed of the Amur River is evidenced by the publication of papers devoted to the program of sustainable land use and rational distribution of lands in the Ussuri River watershed and the Khanka Lake [Kachur et al., 2001], issues on its economic development [Baklanov and Ganzei, 2008], land resource assessment [Karkin and Sheingauz, 2004], and trends of economic interaction between the Russian Far East of Russia and Northeastern China [Tattsenko, 2006]. The common feature of the works in the last few years is that the analysis of the situation within the watershed was made

as a rule by large units of administrative and territorial divisions situated on their territories. The use of such data is complicated because information about the separate parts of the Amur River watershed is often incomplete, diverse, and dissimilar in details, methods of data collection, and processing. Land use was mostly characterized through statistical data without the mapping of wide territories. As a result, the works devoted to LUCC in the region are few in number, and their content is very heterogeneous. Data on land use changes in Eastern Mongolia are very rare and incomplete.

Northeast China has considerably been studied better on the basis of LUCC methodology. At the same time, available data from publications in the 20th century are widely diversified regarding the studied areas and duration of analyzed periods. Generally, works estimating long-term changes are rare. One of the exceptions was a set of works by Professor Himiyama. Under his leadership, The Land Use Map of Northeastern China was compiled in 1995, which allowed the study of spatial land use and land cover structures from the 1930s and the assessment of land changes for a 70-year period [Himiyama et al., 1995; 2002]. Previously we have also provided data on LUCC in the Amur river basin [Ganzei et al, 2007, 2009, 2010].

MATERIALS AND METHODS

Land cover/land use map for 1930–1940s

An inventory of different materials containing information on land cover/land use statements in the 1930–1940s in the Chinese, Russian, and Mongolian parts of the Amur Basin showed that topographical maps published during the same period were the main source of land use data, and that it was possible to compile the Land Cover Map of the Amur River Basin during the 1930–1940s on their bases [Ganzei and all, 2009].

The map was compiled through an analysis of the topographical sheets of

the Amur River watershed printed mainly in the 1930s–1940s in different countries and in various scales (1:100,000; 1:200,000; 1:250,000; 1:300,000; 1:420,000, 1:1,000, 000). In all, the topographical sheets totaled more than 1500. The maps of land use in the Chinese part of the watershed were compiled through an analysis of topographical sheets (scale 1:100,000), and were compiled for Manchurian territory in 1930 by the General Staff of the Kwantung Army of Japan. It was checked by the General Staff of the Military/Air Forces of the USA using topographical maps in the scale of 1:250,000 made for the Manchurian territory between 1949 and 1952. Published in the former USSR in the 1930s–1940s, the maps (scale 1:100,000–1:1,000,000) were also used to draw the near-border forest areas of China. The Mongolian part of the watershed was characterized through an analysis of topographical maps in the scale of 1:100,000, 1:200,000, and 1:1,000,000 compiled in the USSR in the 1930s–1940s. The maps in the scales of 1:300,000 and 1:200,000 contained more detailed information about the land cover and land use in the territory. We could identify additional characteristics such as forest types (coniferous, mixed, and deciduous – partly divided), grasslands, sparse forests and bushes, forest cutting area, burned-out forests, salt-marshes, sand ground, dry lands, and settlements. Maps in the scale of 1:100,000 showed the same types of land cover and land use as in the 1:300,000 and 1:200,000 maps. Additionally, these maps allowed us to define the boundaries between arable (dry) lands and paddy fields. The forest types (coniferous, mixed, and deciduous forests) had a presumptive character (for the whole watershed).

Land cover/land use map for 2000s

A set of satellite images from Landsat-7 (USA) in 2000–2001 provided the initial basic information for drawing the map “Modern Land-Use in the Amur River Watershed” [Ganzei and all, 2007]. Composite compilations of the average resolution from 30 m and more were used in the work. The

satellite images from Landsat TM with a resolution of 15–30 m were used to specify some of the most disputed territories. Decoding was made via GIS ArcView 3,3 and ArcGIS software using a special extension Image Analysis to form shape files and their subsequent conversion to Arc/Info coverings. The next information was converted to electronic raster and then to vector format: a map of the vegetation of the Amur River watershed in the scale of 1:2,500,000 edited by Sochava [1969], a map of the vegetation of the Mongolian National Republic [1990], a map of the vegetation of China from the Atlas of Vegetation of PRC [2001], Raster topographical maps in the scale of 1:500,000. It was necessary to create a uniform classification of land use types since the classifications accepted and used in China, Russia, and Mongolia differed significantly.

The classification of forest lands has been corrected. In addition to the density of wood stands, their typological characteristics have been introduced. Coniferous, mixed, and deciduous forests, sparse forests, and other forests have been further defined in forest lands. Since the mapping scale is small enough, and the level of generalization is high, each type's concept includes various kinds of land use and natural states of lands. In these, the genesis of each type of land is not considered; they can be formed through very different ways. The "coniferous forest" type includes fir, abies, Korean pine, pine, larch forests, and their other species. The "mixed forest" type includes all transitive versions from coniferous to deciduous forests at approximately equal ratios. The "deciduous forest" type includes broad-leaved and small-leaved forests and their other species. The "sparse forests" type includes rare forests of various compositions, alternating with woods with bushes of density stands less than 30%. Again, as already mentioned above, the genesis of this type of lands is not considered; they can be formed after fires, loggings, and so on. The "other forests" type includes forest and industrial plantations. The category "meadows and bushes" describes meadows, bushes, and by-golets

bushes with high-mountainous tundras. The "bushes" type includes bushes, meadows, and bush lands, partly, bush and sparse forested lands with a prevalence of bush vegetation. The "meadows" type is rather varied, and at any given stage in the study, it includes any grassy vegetation: usually meadows, steppes, and so on. The "golets bushes with high-mountainous tundras" type includes mountainous pine, dwarf forms of high-mountainous bushes, tundras, and golets. The "agricultural lands" category describes reclaimed and unreclaimed agricultural lands. The "reclaimed lands" type includes paddy fields, and the type "unreclaimed lands" includes arable lands, fallow lands, haymaking sites, and pastures. The "water bodies" category embraces lakes, water reservoirs, swamps. The "wetland" type includes swamps, high bogs, and water-logged flooded meadows and marshes. Fire-sites and loggings at locations of former forests, residential areas (large settlements), and industrial and unused lands (quarries, slag-heaps, etc.) enter the category "other lands."

RESULTS

Land cover/land use status in the periods of 1930–1940 and 2000–2001

The thematic content of the topographical maps allows us to use 18 land use types for compiling the land cover map of the Amur River basin from 1930–1940 (Fig. 1, Table 1). According to these data, 53,1% of the basin were occupied by forests, 17,6 % by grassland, 13,2 % by wetlands, and 16 % of dry land. Over 63% of the Basin's forest land, 57,7% of wetlands, and about 72% of urban lands were situated in Russia in the 1930–1940s, and 91,1% of dry lands and 55% of grassland were in China.

The map of modern land use in the Amur River basin is more detailed in thematic content and contours of different polygons (Fig. 2).

At present, forest areas occupy over half (54,3 %) of the watershed territory (Table 2). Over 30% of this area is occupied by mixed

Table 1. Land Cover and Land Use in the Amur River Basin in 1930–1940

Land use type	Total (km ²)	Russia (km ²)	China (km ²)	Mongolia (km ²)
Coniferous forests	189 448	155 635	30 815	2 997
Mixed forests	686 902	495 434	179 367	12 099
Deciduous forests	180 500	17 064	163 354	81
Sparse forests	25 745	14 794	7 931	3 018
Sparse forests and bushes	64 386	31 586	20 502	12 297
Bushes	40 032	27 968	106	11 957
Bushes and grasslands	28 835	5 858	22 311	665
Grassland	358 445	46 022	195 201	117 221
Dry farmands	136 782	12 177	124 605	–
Wetlands	270 251	155 892	111 166	3 192
Lakes and reservoirs	9 086	5 589	2 858	639
Urban lands	308	221	87	–
Forest cutting area	2 144	2 144	–	–
Burned-out forests	17 864	17 689	–	175
Mountain tundra	21 245	20 980	–	265
Salt-marsh	5 024	954	273	3 796
Sand ground	2 302	–	2 014	288
Paddy fields	545	–	545	–

Table 2. Land Cover and Land Use in the Amur River Basin in 2000–2001

Land use type	Total (km ²)	Russia (km ²)	Mongolia (km ²)	China (km ²)
Coniferous forests	277 610	214 035	8 411	55 163
Deciduous forests	315 971	118 255	3 080	194 635
Mixed forests	347 253	231 010	6 161	110 081
Sparse forests	145 396	106 318	4 583	34 495
Burned-out forests	27 156	26 365	491	300
Other forest lands	4 976	–	1 811	3 165
Grasslands	248 664	24 469	135 076	89 118
Paddy fields	25 982	2 370	–	23 612
Dry farming lands	346 695	81 053	2 311	263 330
Lakes	10 619	5 189	815	4 614
Reservoirs	2 493	2 040	–	452
Wetlands	139 929	95 308	44	44 576
Urban lands	2 666	991	–	1 675
Unused lands	657	611	–	45
Mountain tundra	13 304	12 783	131	388
Waste ground	222	186	–	36
Bushes	121 597	82 303	5 777	33 517
Forest cutting area	8 655	6 721	–	1 933

and coniferous woods situated mainly in the Russian territory. It is necessary to note that the majority of fire-sites, loggings, and sparse forests are also located in the Russian territory, which reflects adverse trends in forest management, developed on our territory in the 1990s. Deciduous forests occupy about 15 % of all forest lands.

Agricultural lands occupying nearly 20% of its territory are the second type of lands in the area of the watershed. The dominant share of cultivated lands including irrigated land is located in the Chinese part of the watershed. Prompt reduction of wetlands is one of the consequences of its active agricultural development. According to Chinese researchers [Liu et al., 2004], a share of wetlands on the Sanjiang Plain for the period from 1950 to 2000 was reduced by 52,5%, from 32,4 thousand km² to 9,2 thousand km². At the same time, the share of agricultural lands increased from 10,2% to 55,1%. Most of the wetlands are located still on Russian territory.

Meadows and bushes also make up about 20% of the area of the Amur River watershed. The territorial distribution of the types of modern land use reflects both the natural and climatic conditions of the territory, as well as the national features of nature management, and the historical and modern trends in development of the economy of the countries involved.

In the Chinese territory, coniferous forests occupy the largest area within the Great Khingan Ridge in Inner Mongolia Autonomous Region, measured at 25,3 thousand km². Mixed forests prevail in Heilongjiang Province, measuring 59,7 thousand km² or about 54,2% of the area of the forests in the Chinese territory. Decoded satellite images allowed us to reveal other features of the modern state of forests in Chinese territory. It was observed that there existed a considerable divergence between the data of the Atlas of Vegetation of the PRC (2001) and the decoded data. For example, the northern portion of the Great Khingan Ridge is shown in the Atlas of Vegetation as a zone with a practically continuous distribution of

coniferous forests. However, the decoded data show that at present, deciduous forests dominate the area, and that coniferous and mixed forests are typical in the central and southern portions of the Great Khingan Ridge. A high share of timber cuttings in Jilin Province, about 36,3% of the logging area in the Chinese part of the watershed, also appeared to be unexpected. Besides, it is necessary to take into account that used data may not reflect the present situation in full because objects in areas less than 50 km² have not been displayed on the final map.

Wide spectrum of land use is characteristic of Dornod Aimak of Mongolia. Deciduous forests dominate the forested lands, with a share of up to 24,7% of the forests in the Mongolian portion of the watershed. The share of coniferous and mixed forests is much less, about 5,6% and 2,3%, respectively. Sparse forests and bushes are widely distributed, reaching 21% and 43,5%, respectively. Approximately half of the meadows of the Mongolian portion of the watershed is concentrated in this aimak. About 86,5% of its agricultural lands are also located in this area.

Long-term dynamics of land cover/land use in the basin

For the estimation of the dynamics of spatial distribution of various types of land cover/land use in the basin, it was necessary to compare the different legends and to create the common legend.

Table 3 provides the scheme of generalization of land use types. All subtypes of forest land were grouped in land use type Forest. Sparse forests and Scrub and Sparse forests were combined into the type sparse forests. The Scrub and Scrub and grassland subtype were combined into the type Bush. Salt-marsh, sand lands, unused land, and waste ground are presented by a common legend and one land use type, Unused land. The analyses of this two maps have allowed us from unified positions and on a uniform scale, to assess the character, structure, and national features of land use of the territories

Table 3. Integrated Legend for the Comparison of Land Cover/Land Use in the Amur River Basin

1930-1940	2000-2001	Joint legend
Conifer forest Mixed forest Deciduous forest	Conifer forest Mixed forest Deciduous forest Other forest land	Forest
Sparse growth Scrub & sparse growth	Sparse growth	Sparse growth
Scrub Scrub & Grassland	Scrub	Bush
Grassland	Grassland	Grassland
Dry farming lands	Dry farm lands	Dry farm lands
Paddy field	Paddy field	Paddy field
Wetland	Wetland	Wetland
Lake	Lake & Reservoir	Lake & Reservoir
Urban land	Urban land	Urban land
Forest cutting area	Forest cutting area	Forest cutting area
Burned out forest	Burned out forest	Burned out forest
Mountain tundra	Mountain tundra	Mountain tundra
Salt-marsh Sands	Unused land Waste ground	Unused land

of Mongolia, China, and Russia included in the Amur River watershed.

A comparison of the two compiled maps shows an essential decrease in the area and simplification of the structure of forests

towards a prevalence of invaluable woods (Table 4). This especially concerns the northern and eastern parts of the Great Khingan Ridge, Less Khingan (both in the Russian and Chinese portions), northern portion of Sikhote-Alin Ridge, and Chitinskaya

Table 4. Land Cover and Land Use Changes in the Basin

Land use type	1930–1940 (km ²)	2000–2001 (km ²)	Change (km ²)	1930–1940 (%)	2000–2001 (%)	Change (%)
Forest land	105 7016	945 812	–111 204	51.8	46.4	–5.5
Sparse forest	97 306	145 397	48 090	4.8	7.1	2.4
Bush	68 703	121 598	52 894	3.4	6.0	2.6
Grassland	351 270	248 664	–102 606	17.2	12.2	–5.0
Dry farming lands	136 783	346 696	209 913	6.7	17.0	10.3
Paddy field	546	25 982	25 437	0.0	1.3	1.2
Wetland	270 251	139 929	–130 322	13.2	6.9	–6.4
Lake & reservoir	9087	13 112	4026	0.4	0.6	0.2
Urban land	309	2666	2358	0.0	0.1	0.1
Forest cutting area	2689	8655	5967	0.1	0.4	0.3
Burned-out forest	17 423	27 365	9943	0.9	1.3	0.5
Mountain tundra	21 144	13 177	–7967	1.0	0.6	–0.4

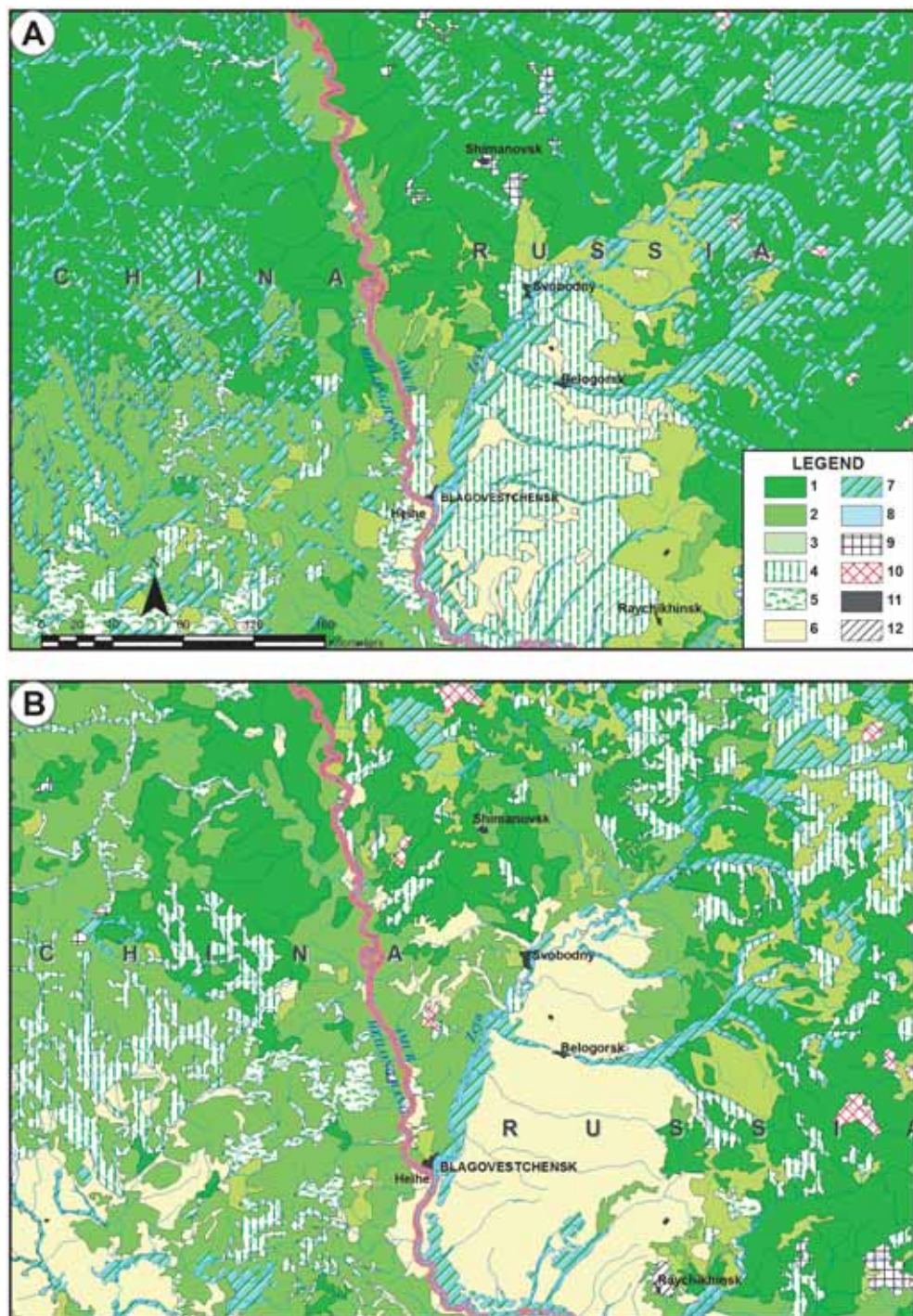


Fig. 3. The Xioxing Anling and Zeya-Burea plain. Forest and Scrub lands:

A – in 1930–1940s, B – at the beginning of the XXI century.

1 – coniferous and mixed forests; 2 – deciduous forests; 3 – sparse growth; 4 – bushes; 5 – grassland; 6 – dry land; 7 – wetlands; 8 – lakes and reservoirs; 9 – forest cutting area; 10 – slash fire; 11 – urban land; 12 – unused lands

Oblast. About 78% of the cut down forests in the Amur River watershed and 97% of the forests burned in 2000–2001 are on the Russian territory. In total, forests have lost about 111.2 thousand km² of their area since 1930.

A significant expansion of the area of agricultural lands that occurred in the People Republic of China from the 1930s and in 2000–2001 has been observed. These changes concern the Xioxing Anling and Zeya-Bureya plain (Fig. 3) and the Sanjiang Plain (Fig. 4). In many cases, these changes are associated with a reduction in the area of wetlands and forests. Wetlands lost an area of about 130,3 thousand km² in the basin. Most parts of wetlands are still concentrated on the Russian part of the watershed.

DISCUSSION

Data accuracy

It is necessary to notice that the legends of the topographic maps published in Japan and in the USSR are essentially different. The legends of the Japanese maps are more detailed especially for the developed agricultural areas, these types of land use were practically not shown on the maps in the scale of 1:100000 published in the USSR. The Japanese maps for flat territories that were economically developed are distinguished for their accuracy and are compiled with a high degree of reliability. Topographical maps of mountain forest territories contain a lot of errors: in hydronetwork drawing, in the width of river valleys, in the border position of forest territory, and in the characteristics of forests. For the Russian and Mongolian parts of the watershed, the borders of forested territories, wetlands, burnt-out areas, felling areas, meadows, sparse forests, shrubs and sparse forests, shrubs, mountain tundra, steppes, salt marshes, sand lands, and water objects and large settlements are defined with a high degree of reliability. In most cases, the borders are of the type forest. One of the key questions in this study is concerned with the reliability of comparisons obtained. In our opinion, one can determine with a high level of confidence only the general tendencies in the spatial dynamics of land distribution within the Amur River basin.

Forest lands

Sheingauz A.S. [2006] identified several periods in the economical use of Far-Eastern forests, noting meanwhile the complex spatial-temporal dynamics of volumes and heaviness of felling. From 1900 to 2000, he revealed two peaks of felling which coincided with the periods of 1930s–1940s and 1980s. During the first of these periods, the most intense felling was noted in the Zeya-Bureya plain and the Amur-Zeya Plateau in Amurskaya Oblast (Fig. 3), and on the western macroslope and foothills of the central and southern Sikhote-Alin in Primorskii Krai. By 2000, a zone of intense felling had shifted to the northern part of Sikhote-Alin. Felling had also remained quite high within Little Khingan. A.S. Sheingauz notes that the Amur zone of intense felling had disappeared by 2000. This fact was also confirmed in our cartographic estimates of the spatial dynamics of forests and their felling within the Amur River basin.

In the Chinese portion of the basin, the basic felling in the 1930–1940s was concentrated around the mountain massif of Changbaishan and Little Khingan ridge [Zhang, 2000; He et al., 2008], which was partly related to the construction and subsequent operation of the railway between Harbin and Jiamusi. From 1931 to 1945, the forest area within Little Khingan and the Sungari River basin decreased by more than 10,1 million hectares [Glushakov, 1948]. From 1949 to 1998, the area of forest land in the Autonomous Area of Inner Mongolia decreased by 5%, while it increased by 5–10% in Heilongjiang and Jilin Provinces [He et al., 2008]. North-eastern PRC has remained in the 20th century to be one of the main suppliers and consumers of timber [Yamane, 2007]. The area of forests has, to the largest extent, decreased on the western and eastern spurs of the Great Khingan mountains, in western and northern Sikhote-Alin Ridge, within Little Khingan ridge (Russian and Chinese parts), and in the Amurskaya and Chitinskaya Oblasts. Although this process was characterized by a stable negative trend, there are regions where the forest areas have increased owing

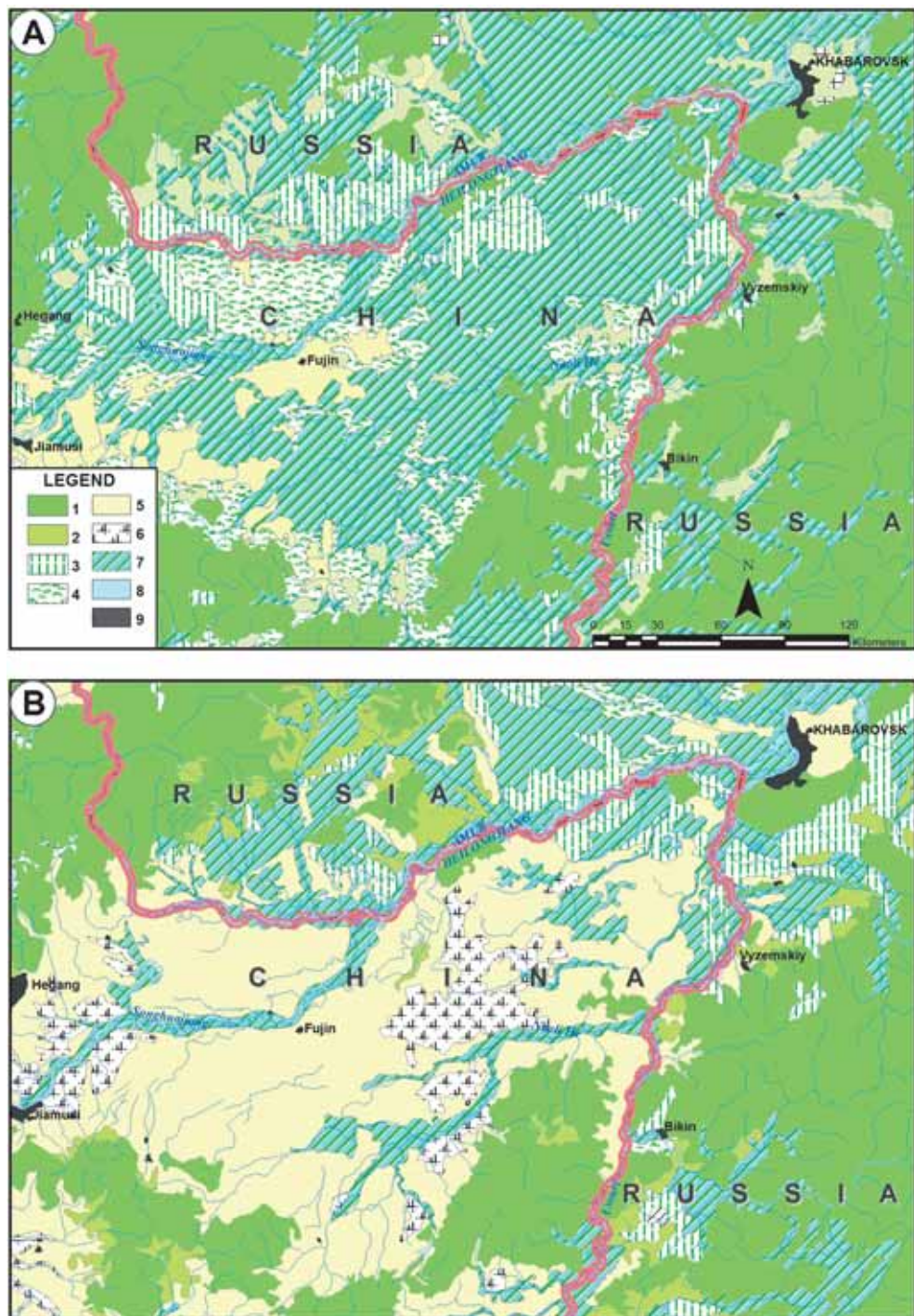


Fig. 4. The Sanjiang plain. Agricultural lands and wetlands:

A – in 1930–1940s, B – at the beginning of the XXI century.

1 – forests; 2 – sparse growth; 3 – bushes; 4 – grassland; 5 – dry land; 6 – paddy field; 7 – wetlands;
8 – lakes and reservoirs; 9 – urban land

to active reforestation police, especially in the southern part of the Great Khingan ridge.

Agricultural lands

The cleared forest areas were often used for farm production. According to data of K. Nakagane [1982], the area occupied by crops in three north-eastern provinces of China increased between the period 1932–1942 by 17,7%. This figure agrees with the estimates of Russian geographers [Glushakov, 1948]. The lands sown with rice increased on the average by 2% [Nakagane, 1982]. The expansion of the area under cultivation was, to a large extent, related to the continuing development of the Nongjiang-Sungari lowland and the southern, most suitable for agriculture portions of the North Khanka plain.

According to the data of Tibekin A.R. [1989], crop areas between the period of 1930–1940 increased by 57,3 % in Amurskaya Oblast and by 66,7% in Khabarovskii Krai (Russian territory). In Primorskii Krai they decreased by 13,3% in connection with the resettlement of Koreans to various locations in Central Asia and Kazakhstan. The Zeya-Bureya plain and Khanka and Middle-Amur lowlands were subjected to the most development.

In the Russian part of the basin, there was a decrease in crop areas as compared to the pre-crisis period [Baklanov and Ganzei, 2008]. In the Chinese part of the basin, meanwhile, new territories were developed. On frequent occasions, this development was related to the conversion of water-marshes and meadow lands to agricultural land use. This process was characterized as intense development in the Sangjiang plain [Liu et al., 2004; Wang et al., 2006]. From 1980 to 2000, areas of meadows and water-marsh lands in the Nongjiang-Sungari lowland were reduced by more than 25% and 8.5%, respectively. The changes on the Sangjiang plain were more significant. From 1950 to 2000, the area of water-marsh lands decreased by 52,5%, while that of arable land increased by 45% (Fig. 4). Overall, the stable

tendency of increasing areas for agricultural lands was observed in all parts of the basin.

Cartographic analysis of the patterns of land distribution within the Amur River basin over the last 70–80 years, numerous investigations of Russian and foreign authors, and statistical data allowed us to confirm and quantitatively characterize the basic tendencies of spatial variations of land use within a great subregional trans-boundary geosystem. The general tendency in land distribution change is characterized by a reduction in areas of natural lands (forests, water-marsh lands, and meadows) and a swift increase in anthropogenically transformed landscapes (agricultural landscapes, burnt-outs, and coupes).

CONCLUSIONS

Cartographic analysis of the distribution of land use in the basin of the Amur River over the past 70–80 years, numerous studies of native and foreign authors, statistical materials made it possible to identify the main trends in the use of land in major subregional cross-border geosystems.

The compiled electronic maps are, in first, an information basis for carrying out of the further analysis of system of land-use in Amur River watershed, and, in second, as an electronic layer it is a component of forming geo-information space of the whole Amur River watershed.

Therefore studying of all complex of the problems influencing on efficiency of land use and an ecological condition in the trans-boundary river basins, and also the factors breaking their structural organization and functioning, is one of the primary goals for development of the program of sustainable land use which should be created for all basin.

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SPATIAL AND TEMPORAL DYNAMICS OF THE BAIKAL COASTAL LINE CAUSED BY CONTROL OF THE LAKE LEVEL REGIME

ABSTRACT. The paper presents the results of a study on changes in the coastal line of the Yarki islands (North Baikal) using remote sensing data of the Earth. Vector shape files were generated from the automated classification of the multi-temporal Landsat data. The analysis suggests a systematic decrease in the Yarki's sandbar area.

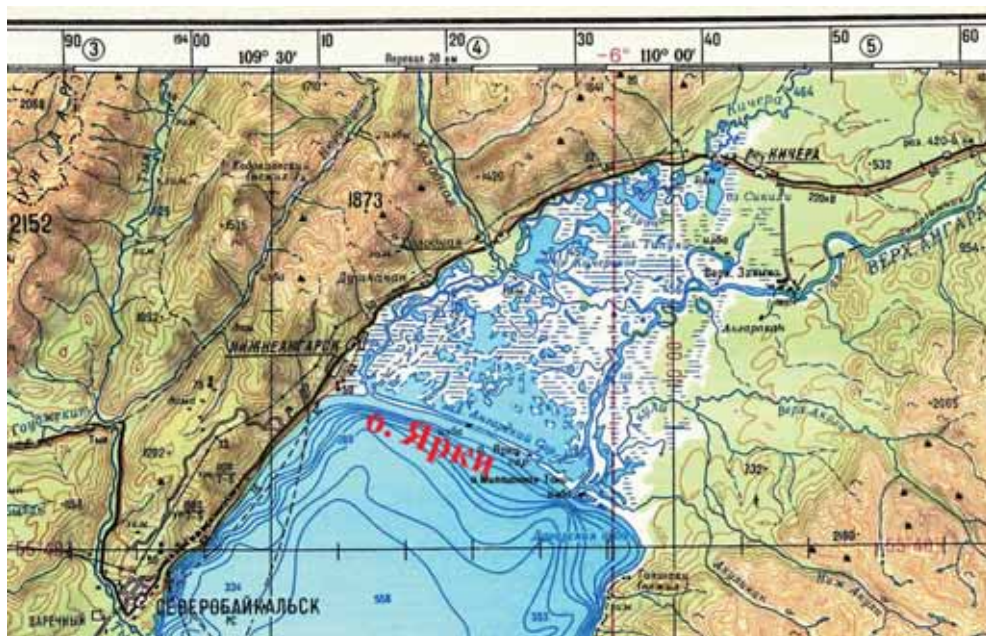
KEY WORDS: remote sensing, multispectral image, interpretation, automated classification, vector layer

INTRODUCTION

After commissioning of the Irkutsk hydroelectric power station in 1957 and of the subsequent cascade of the Angara hydroelectric power stations (the Bratsk and the Ust-Ilim), by 1959, the average level of Lake Baikal rose by more than 1,2 m in relation to its natural level (455,61 m; here and further, measured in the Pacific Ocean system), which has led to the formation of a new hydrological regime of the lake [Galaziy, 1988]. Thus, at present, the level of Lake Baikal for the most part does not depend on natural factors but is heavily influenced by the Angara hydroelectric system [Monitoring ..., 1991]. The intra-annual fluctuations in the lake level increased from of 82 cm (under its

natural regime) to 94 cm (after the control implementation) [Atlas..., 1993]. The rise of the lake level had a negative impact on the productivity of the aquatic flora and fauna, biodiversity, water birds and animals, and has led to the erosion of the coastline. The end-result of the construction of the Irkutsk hydroelectric station is the transformation of Lake Baikal into an artificial reservoir with all the ensuing consequences.

During high-water years of the mid-1990s, there were level marks well above 457 m. As a consequence, there was a mass destruction and erosion of the coastline of the low eastern coast (coastal forests, recreation areas, beaches, and coastal structures), water logging, and flooding of agricultural land and settlements. There has been a widespread environmental damage to the natural biological complex of the lake system. There are estimates of the economic damage to the economy of Buryatia; there is also a negative experience with the litigation of JSC "Irkutskenergo" [Hydropower..., 1999]. In order to prevent such processes, the Government of the Republic of Buryatia in agreement with the Irkutsk Oblast Administration initiated the adoption of the 2001 Resolution of the Government of the Russian Federation № 234 "On the limits of the water level in Lake Baikal under



**Fig. 1. A fragment of a topographic map 1:500 000 scale (the North Baikal region).
(The name of the Yarki islands is shown in red.)**

economic and other activities". This by-law of the Federal Law "On Protection of Lake Baikal" regulates the lake level fluctuations in the range of 456 to 457 m.

A real threat of a complete destruction of the Yarki islands requires individual consideration; these islands separate the open Baikal from the Verkhneangarsky shoal (Fig. 1). The Yarki is a sandy island system of 17 km in length and 200 m in width. The sandbar of the island is near the village Nizhneangarsk; the mainland is separated from the islands by the estuaries of the Kichera and the Upper Angara. Picturesque scenery, warm water (the lake warms up to 24°C), and long sandy beaches make Yarki one of the most attractive holiday destinations in the North Baikal area.

If the lake level approaches 457 m and under 3–5 day-straight specific wave conditions, the Yarki island system could just disappear and the cold Baikal water could destroy the entire unique ecosystem of the shallow area of the Upper Angara

and the Kichera deltas, including the Upper Angara race of omul; the length of Lake Baikal could extend 40–40 km to the north. There will be changes to the entire lake basin and to its water level regime.

Wave activity within the entire extent of the shore from the village Nishzneangarsk to the Dagara with the estuarial part of the Upper Angara River, has been already incapable of supplying the inflow of suspended sandy particles with floodwater. Consequently, the volume of the incoming sedimentary material not only does not compensate the occurring destruction of the Yarki islands, but does not even maintain the conditions that had existed prior to the construction of the Irkutsk hydroelectric system before the rise of the lake level to the top of the flood-control capacity. [Potemkin, Suturn, 2011]. According to the estimate of A.L. Rybak who has conducted lithodynamic research in this area, the long-term annual rate of erosion of the islands is 0,8–1,0 m/yr. Consequently, the complete destruction of the Yarki may occur in the nearest 30–40 years [Ymetkhenov, 1997].

THEMATIC CLASSIFICATION OF THE NATURAL ENVIRONMENT

The paper analyzes changes in the coastline of the Yarki islands based on remote sensing data. Regular space image collection is an objective and timely representation of the conditions of the Earth's surface and of its changes; modern geoinformation technologies of space imagery processing provide for precise georeferencing of multi-temporal data for studies of changes occurring on the Earth's surface. We have chosen the algorithm of the automated classification of satellite imagery for the optimal interpretation and automated zonal classification of the territory.

The procedure for satellite interpretation used in our work involved:

- 1) download of orthorectified Landsat imagery from the Internet;
- 2) image-processing – synthesis of the RGB-composites, coordinatewise isolation of necessary fragments;
- 3) objects' interpretation (thematic classification followed by generalization);
- 4) creation of thematic layers and editing;
- 5) compilation of the final map of the coastline changes of the sandbar.

Image processing was conducted using ENVI 4.7 + ENVI EX software application (www.ittvis.com/ENVI) that includes the most

complete set of functions for remote sensing data interpretation and GIS processing. The thematic vector layers created were processed using ArcView3.3.

Mapping of the Yarki island system was based on the multi-temporal and multi-spectral imagery. The data were downloaded from the geoportal of the US Geological Survey (USGS) through the GloVis search system; four "summer" scenes of the Landsat platform were downloaded because the summer period is characterized by stability, duration, and the best quality of light conditions:

- 1) July 3, 1994 (spectroradiometer TM, cloudiness – 0%, image quality – 9);
- 2) August 12, 2000 (spectroradiometer ETM+, cloudiness – 17%, however, no clouds in the study area. therefore, image quality – 9);
- 3) September 22, 2006 (spectroradiometer TM, cloudiness – 0%, image quality – 7);
- 4) August 29, 2009 (spectroradiometer TM, cloudiness – 0%, image quality – 7).

Due to the nature of the Landsat satellite paths, it was not possible to download scenes for the same time-period. Even if the scenes were close in date, other factors interfered: cloudiness and poor image quality; in any case, we tried to obtain the scenes close in dates.

One of the main directions of the use of multiband images is the synthesis of color

Table 1. Spectral bands (channels) of the radiometer Landsat TM and ETM+

Channel number	Resolution, m	Band	From, nm	To, nm
1	30	Blue	450	515
2	30	Green	525	605
3	30	Red	630	690
4	30	Near-infrared	760	900
5	30	Middle infrared – 1	1550	1750
6	60	Far infrared	10400	12500
7	30	Middle infrared – 2	2080	2350
8	15	Panchromatic	520	900

images for visual interpretation with the subsequent automated classification. It is feasible to conduct object definition and delineation using images with intentional false color rendering. We used synthesis of: the near infrared spectral band – red color, the first middle infrared band – green color, and the red visible band – blue color, i.e., we created a pseudo-colored RGB-composite with a combination of channels 4:4:3 (Table 1). This combination of channels allows distinct differentiation of the land-water boundary and accentuation of hidden details poorly visible with the channels in the visible band only. As water gets deeper, it looks darker (including black color), which is associated with its absorption of the infrared light.

The fragments ($21,5 \times 11,7$ km) that completely encompass the Yarki were cut from the obtained RGB-composites.

The next phase involved obtaining the Regions of Interest (ROIs). Because the task was to differentiate between land and water and water is relatively uniform in terms of spectral brightness and has the lowest values of the reflective coefficient in comparison with other natural objects (i.e., it almost never overlaps them in terms of brightness), we selected polygonal objects on water and land, which were later used as the training sets for the classification with training.

We used the supervised (i.e., with training) classification with rectangular method to isolate coastline. This method is used in cases when values of spectral brightness of different objects practically do not overlap and there are only few classes present. As it follows from the name, in the classification of spectral parameters, rectangular areas are isolated and these areas delineate the brightness values for the objects of this class. Then, the values of the spectral parameters in each pixel are compared with the limit values (minimal and maximal) in each class. If a pixel brightness parameters fit within one of the isolated ranges, it is included in this class. If the brightness parameters of a pixel

do not fit in any range, it is included in the unclassified objects. If the brightness values fit within several ranges, several options of object classification are possible.

Two types of the standard sites were selected as the training sets: water surface and land. For each type of the standard sites, we have calculated the average value of pixel brightness and the standard deviation of brightness. The maximal standard deviation from the brightness mean in the “water” class did not exceed 2, which is associated with a relatively uniform characteristics of this object class. The downside of this isolation method is a partial overlap of the brightness parameters of the sandbar shoal and land; these overlaps were eliminated in subsequent processing [Tulokhonov, 2010].

In addition, in order to differentiate between the land and water surfaces, we used the algorithm of the unsupervised classification (the ISODATA method – the Iterative Self-Organizing Data Analysis Technique). It is feasible to use this algorithm in the absence of prior information on a survey object. The method allows delineating contours with a non-contrast (in terms of spectral brightness) structure. We have selected the optimal (in our opinion) parameters: number of classes – 2, maximal number of iterations – 20, convergence limit (a number of pixels that change their class with the next iteration) – 5%, maximal standard deviation from the mean – 13, minimal number of pixels for class isolation – 3, maximal standard deviation inside a class – 5, and minimal spectral distance – 5 pixels.

After the unsupervised classification, a classification map was obtained; the map reflects more objectively the groups of objects with close in values interpreted parameters compared with the supervised classification, because the clusters are identified automatically. However, the obtained map of the classification required further merging and splitting of classes because the same objects may be in different clusters (for example, due to light

Table 2. The area of the vector layers of the sandbar Yarki

№	Name	Year	Area, km ²
1	1994-4-5-3_isle.shp	1994	2.524
2	2000-4-5-3_isle.shp	2000	2.052
3	2009-4-5-3_isle.shp	2009	1.855

conditions) and different object can be present in the same cluster (due to similar brightness). In the first case, the clusters were merged within the same class, while in the second case, in order to separate the objects, additional interpretation parameters were used.

The land areals on the images obtained through the unsupervised and supervised classification appeared to be similar. This is due to the fact that land on the images is relatively uniform in spectral brightness and the water-land boundary is defined clearly because of the reflective properties of the water surface in the utilized combination of the Landsat channels.

The next step in the interpretation of the sites "water-land (non-water)" was the post-classification processing using "majority analysis." The purpose of this method is to enhance perceptance of the recognizable objects and to reduce noise and other random errors, in other words, to perform image generalization. In the course of processing, changes in the size of each pixel of the images occurred depending on the values of adjacent pixels in a sliding window of 3×3 pixels in size.

After the post-classification, the obtained raster images were converted into the vector format. Then, the interpreted contours of the water and land sites were edited in order to obtain only the vector layers of the sandbar.

The image for 2006 could not be post-classified correctly due to a poor quality of the image (the water surface in some places looks albescent and blends in with the sandbars). As a result, 3 multi-temporal vector layers have been obtained: for 1994, 2000, and 2009. There is a distinct systematic reduction in the area of the Yarki sandbar in 2009 compared with 2000 (by 0,2 km²) and 1994 (by 0,7 km²) (Table 2, Fig. 2–3).

It can be seen that the islands continue to deteriorate and that the coastline is primarily destructed on the lake's side. The main cause of the destruction of the Yarki is the rise in the water level and wave impact. The amplitude of the fluctuations of the water level at its 1 m rise and with controlled run-off has increased in the long-term. This has led to the activation of abrasion processes [Dynamics ..., 1976].

In order to measure the width of the sandbar Yarki digitally using the GPS mapping

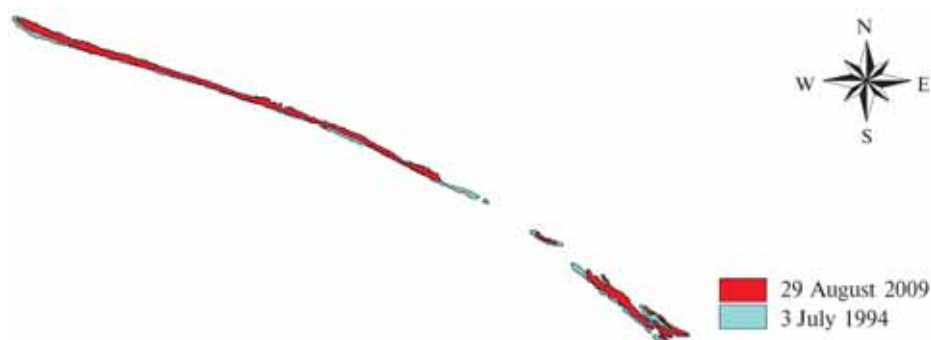
**Fig. 2. Comparison of the vector layers of 1994 and 2009: changes of the Yarki sandbar**



Fig. 3. Comparison of the vector layers of 2000 and 2009: changes of the Yarki sandbar

software OziExplorer, 2 way points in the widest site of the left part of the island were compared on the 1994 image. The coordinates of points 1 and 2 were saved in the wpt-file of the waypoints; the distance between these points was 243,7 m. Then, the 2009 image was loaded and it was overlaid with the waypoints from the wpt-file (Fig. 4). It can be seen, that the distance between the sandbar edges decreased. One more waypoint was added (№ 3) at the boundary of the sandbar in 2009. The distance between

waypoints 1 and 3 was 158,6 m. Thus, the width of the island has decreased from 243,7 m in 1994 to 158,6 m in 2009; the difference is 85,1 m.

It is important to emphasize that the catastrophic activation of the coastal processes observed at present has been specifically caused by technogenic factors: the backwater effect of the hydrocomplex. The intense destruction of vegetation by recreating people in the Yarki has enhanced dune deflation and island flattening [Vicka et al, 2006].

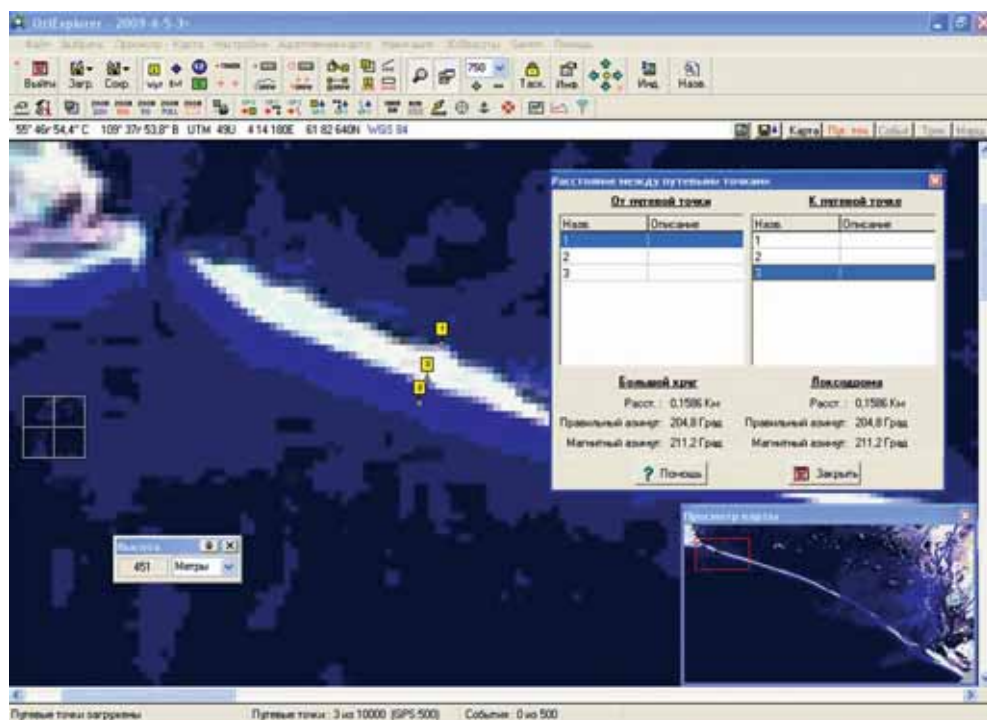


Fig. 4. Changes in the width of the Yarki sandbar on the 2009 image. The sand shoals are in light blue. In the window (bottom right) the entire system of the Yarki islands is shown

CONCLUSION

Many islands of the Yarki system have been destructed by wave impact. In the fall storm period and at southern winds, surging associated with the nature of the spatial contours of the lake and the wind regime determine a substantial increase of the lake level in its northern part over the limit levels identified in the federal law. Specifically this situation causes the intense destruction of the Yarki island system – there are substantial changes in the sand islands and in bay-, beach-, and shoal-bars. Moreover, even at the existing water level regime, the destruction of the Yarki in the nearest future may cause the expansion of the cold Baikal water further north with the catastrophic consequences to the biota of the estuarial areas of the Kichera and the Upper Angara.

These circumstances give reason to preserve ecologically balanced system and to raise the question of the control of the water level regime within the average long-term fluctuations that existed before the construction of the Baikal Irkutsk hydropower complex, when fluctuations were in the range of 82 cm. Of course, this greatly complicates the task of hydropower electricity generation and requires its seasonal spread. However, this scenario is realistic, provided a sufficient number of hydrological stations exist and accurate weather forecasts are possible to allow storing in advance or releasing water of the Irkutsk reservoir.

With a lack of hydro-meteorological information, the need to increase the

productivity of shallow waters of Baikal, and development of the tourism industry in the special economic zones, it is necessary to be more careful in respect to the coastal processes. This problem can only be solved with the mandatory legislative decrease of the amplitude of the minimal and maximal levels of the Lake Baikal water to the natural conditions prior to the construction of the hydropower system. In order to obtain timely information on the water level regime, to improve forecasting, and to avoid the influence of different natural phenomena on the water level of the lake within its entire area, it is necessary increase to the number of the gauging stations on the eastern and northern coasts of Lake Baikal. First, at the sites protected from the intense wind activity, for example, in Istomino, Lemasovo, Chyvyrkuysky and Barguzynsky bays, and north of the Yarki island system.

The conclusions of this paper are preliminary and at this time, it is difficult to speak with certainty about a consistent coastline retreat over a hydrological year based only on the analysis of the remote sensing data. It is difficult to quantitatively assess the rates of modern processes of coastal retreat, especially considering the fact that filling and drawdown of Baykal do not occur at a strictly uniform time (it depends on the water content in a particular year, the timing of the filling of the reservoir, the conditions of release of water through the locks of the Irkutsk dam, etc.). For ascertaining the rate of coastal erosion (in m/year) and the situation forecast, further monitoring work is required. ■

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DISTRIBUTION OF METALS IN PARTICLE SIZE FRACTIONS IN SOILS OF TWO FORESTED CATENAS (SMOLENSK–MOSCOW UPLAND)

ABSTRACT. The concentrations and distribution of Fe, Ti, Zr, Mn, Cu, Ni, Co, Cr, Pb, and Zn associated with various particle size fractions have been analyzed in soils of two forested catenas located in the middle Protva River basin on the Smolensk–Moscow Upland. The results showed that concentration of metals in a particular size fraction was defined by a complex of factors: element chemical properties, soil type, genesis of a soil horizon, and position in the catena. A clearly defined relationship between the fraction size and metal concentrations was found for Ti and Zr. The highest levels of Ti were found in coarse and medium silt, while Zr had its highest values only in coarse silt and, in some cases, in fine sand. Such metals as Fe, Mn, Co, Cu and Pb had high concentrations in sand, fine silt, and clay fractions depending on a soil type and a genetic horizon. The maximum load of Cr, Zn, and Ni (in the majority of cases) was found in clay fraction. The minimum loads of Fe, Mn, Co, Cu, and Ni were found in the coarse silt fraction. Variation in concentrations of heavy metals differed depending on particle size. For most metals, the variations were decreasing from coarser to finer fractions.

KEY WORDS: soils, heavy metals, grain-size fractionation, vertical and lateral distribution patterns.

INTRODUCTION

In ecological assessment of the soil cover, it is important to know background (reference) patterns in distribution of toxic elements, specifically, heavy metals (HMs). Texture is proved to be one of the major factors controlling metal concentrations in soils. A wide range of metals is abundant in finer fractions that are more easily trans-located within soil profile and down the slope [Plyaskina and Ladonin, 2005]. However, some aspects of the particle size distribution and its relationship to metal concentrations have not yet been studied. Little is known, for example, about the distribution of metals across particle size fractions in soils of catenary systems. The purpose of this study is to analyze distribution patterns of metals in the particle size fractions in two soil catenas located in southern taiga zone of the Russian Plain.

STUDY AREA

The study area is located 90 km to the southwest from Moscow on the Smolensk–Moscow Upland (314 m asl). The climate of the study area is humid-temperate-continental with moderately moist, warm summers (mean $T_{\text{July}} = 17,5^{\circ}\text{C}$), cold winters (mean $T_{\text{January}} = -9,9^{\circ}\text{C}$), and mean annual precipitation of about 600 mm. The

present-day morphology of the study area is represented by glacial relief on interfluvial dated to the Moscow glaciation and the post-Moscow fluvial relief of river valleys and gullies. Boulder clays, silts, and sands of the glacial and glaciofluvial origin serve as parent materials for soil formation; the most common parent material on interfluvial is mantle loam that overlays all types of the Quaternary deposits. In the soil cover of the study area, podzoluvisols (sod-podzolic soils, according to the Russian classification) with the medium humus content dominate. Natural vegetation varies because the territory is located in the transition zone from mixed to deciduous forests. Typical are secondary mixed small-leaved and spruce or oak and linden-spruce forests that cover about 60% of the studied area. Arable lands and meadows occupy about 40% of its territory.

MATERIALS AND METHODS

Two heterolithic catenas typical of the study area were selected for the research. Catena 1 ends in a local depression – a gully bottom. Catena 2 faces the river valley. Major positions along the catenas were defined and the soils of these positions were described and sampled. Catena 1 included sod-podzolic soils with AEBtC profile (the watershed summit and slope positions) and soddy soils with AC profile (footslope positions). Catena 2 represented a toposequence of sod-podzolic soils and soddy soils at footslope with calcaric features due to the presence of calcareous rock fragments in subsoil (Fig. 1).

Chemical (pH, organic carbon) and granulometric analysis was carried out on 35 samples taken from genetic horizons of the studied soils. 20 samples were fractionated into 6 (1–0,25 mm, 0,25–0,05mm, 0,05–0,01 mm, 0,01–0,005 mm, 0,005–0,001 mm, < 0,001 mm) or 4 size classes (1–0,25 mm, 0,25–0,05 mm, 0,05–0,01 mm, < 0,001 mm) depending on soil position in the catenas (watershed summit soils – 6 fractions; slope-footslope soils – 4 fractions). All fractionated samples of catena 1 and topsoil samples

of catena 2 were analyzed for Ti, Zr, Mn, Cu, Ni, Co, Cr, Pb, and Zn concentrations using quantitative spectral analysis. Fe was determined using atomic absorption. Statistical treatment included correlation analysis and descriptive statistics, and was performed using SPSS.

Two types of coefficients were estimated to describe the vertical and catenary distribution of the elements and particle size fractions: the first, R – coefficient, is the ratio between the studied parameter in a horizon and the same parameter in the parent material of the soil. This coefficient is used to highlight changes that take place during pedogenesis. The second, L – coefficient, indicates granulometric or geochemical differences between soils of summit positions and subordinate landscapes of the lower parts of a catena. For calculating this coefficient, soils of summit positions are used as reference objects.

RESULTS AND CONCLUSIONS

The studied soils differed in terms of general properties responsible for metal mobilization. The soils in the upper sections of catena 2 are acidic and slightly acidic (pH 5,1–6,4) and those of lower sections are neutral (pH 7,2–7,4). The humus content varied from 2 to 4%. The soils of catena 1 are entirely acidic (pH 4,8–5,0). The soils in the lowest section of the catena receive more water and, therefore, show features of gleyzation. The humus content in the soils of the watershed and slope positions and especially in the gully bottom was lower than in the soils of catena 2 (about 2–3% in the soils of the watershed summit and slope positions and 0,7% in the gully bottom).

The results of physical fractionation analysis have shown that B and C horizons of the studied soils are rich in clay. Where podzolization and lessivage take place, the maximum clay accumulation was observed in Bt horizon. An even distribution across the vertical sequence of the soil horizons was typical of medium silt (0,01–0,005 mm).

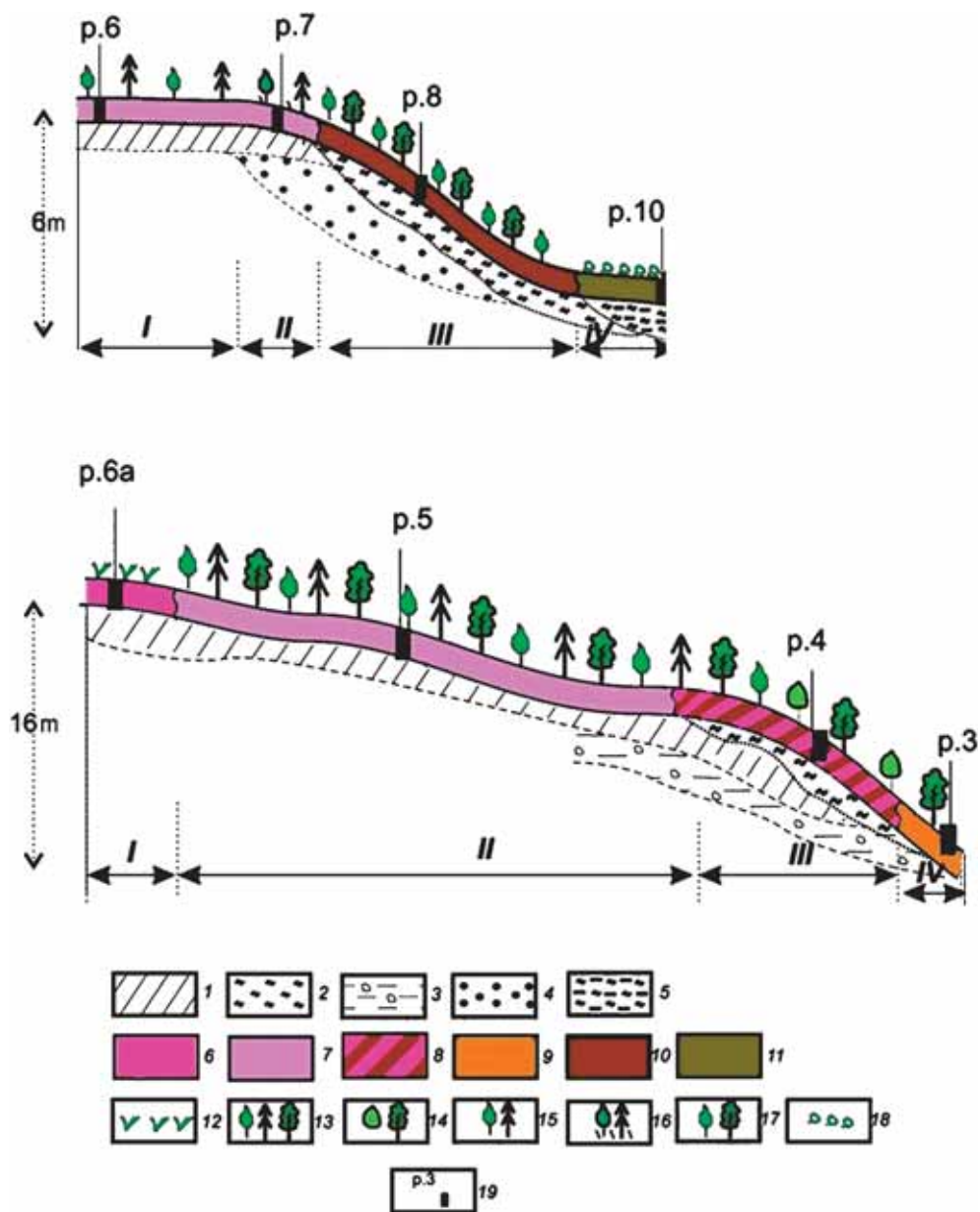


Fig. 1. The studied soil catenas (catena 1 – above, catena 2 – below).

Catenary positions (I–IV): I – watershed summit positions; II–III slope positions;

IV – footslope and toeslope positions;

Quaternary deposits (1–5): 1 – mantle loam, 2 – loamy deluvium; 3 – calcareous glacial loam;

4 – glaciofluvial sands; 5 – loamy deluvium and proluvium;

Soils (6–11): 6 – sod-podzolic soils (podzoluvisols), ploughed in the past;

7 – sod-podzolic soils; 8 – soddy soils with buried horizons of sod-podzolic soils; 9 – soddy soils with calcaric subsoil;

10 – soddy soils; 11 – soddy gleyic soils;

Vegetation (12–18): 12 – meadow; 13 – spruce-oak-birch forest;

14 – oak-linden forest; 15 – birch-spruce forest; 16 – aspen-spruce forest; 17 – birch-oak forest;

18 – forest herbaceous community;

19 – names and locations of the soil profiles

In some cases, this size fraction was abundant in topsoil rich in humus. Fine silt accumulates in humic horizons. The vertical distribution of coarse and medium (1–0,25 mm) and fine (0,25–0,05 mm) sand didn't show any clear patterns. The obtained results indicate that the vertical distribution of two particle size fractions – fine silt and clay – was associated with soil forming processes. For fine silt, it was the accumulation of organic material in the surface horizons, and for clay – a combination of the eluvial and illuvial processes.

The results of chemical analysis of the fractionated soil materials are represented in Table 1. It shows the simple average (in the numerator), minimum, and maximum values (in the denominator) of the HMs concentrations in each of the particle size fractions.

The physical size fractionation of the HMs showed that their concentrations depended on the genesis of both the fractions and the horizons. A clearly defined relationship between the fraction size and the highest concentrations was for Ti and Zr. The highest levels of Ti were found in coarse and medium silt (0,05–0,01 mm, 0,01–0,005 mm), while Zr had the highest values only in coarse silt and in some cases in fine sand (0,25–0,05 mm). High load of Ti in silt fractions have been described by I.G. Pobedintseva [1975] who associated it with the abundance of some primary minerals.

Such metals as Fe, Mn, Co, Cu, and Pb can accumulate in sand, fine silt, and clay fractions depending on the soil type, genetic horizon, and position in the catena. The maximum load of Cr, Zn, and Ni (in most

Table 1. Concentrations of HMs (ppm) in particle size fractions in the soils of the catenas

Metals	Particle size fractions, mm					
	Coarse and medium sand	Fine Sand	Coarse Silt	Medium Silt	Fine Silt	Clay
	1–0.25 n = 19*	0.25–0.05 n = 19	0.05–0.01 n = 18	0.01–0.005 n = 7	0.005–0.001 n = 7	<0.001 n = 18
Pb	16.3 8–43	20 9–37	23.8 17–44	27.1 15–43	38.0 28–49	33.6 20–49
Cr	50.3 20–150	49.4 23–84	64.8 54–88	69.3 54–100	97.9 72–120	112.6 96–130
Co	21.9 7–76	14.6 4–27	9.5 6–30	12.9 8–25	22.6 14–31	24.9 20–32
Ni	44.6 14–88	35.8 13–60	20.1 13–51	32.7 20–63	63.7 42–80	80.5 70–88
Mn	3082.7 330–18000	2840 350–15 000	522.1 350–820	451.4 330–600	717.1 420–1100	1459.3 400–5600
Cu	88.1 26–210	59.7 14–120	22.2 12–78	52.6 21–110	109.4 68–190	107.3 82–200
Zn	46.4 30–130	65.3 30–150	70 40–140	145.7 80–220	208.6 150–300	240 160–370
Ti	1198.2 120–6000	3806.7 1900–7000	8271.4 6700–10 000	8800 1200–12 000	7171.4 5600–11 000	6178.6 4200–9000
Zr	85 50–170	706.4 270–1700	1159.2 850–1500	357.5 250–510	203.3 160–250	173.9 130–210
Fe,%	3.9 0.4–13.9	3.2 0.5–6.9	1.8 0.6–5.2	2.1 1.4–2.4	5.0 3.4–8.0	5.6 4.6–7.3

n – number of samples.

**Table 2. Element associations in the fractionated soil material
(based on the correlation analysis of data for catena 1)**

Particle size fraction, mm	Element groups	
	Correlation between elements is significant at 0.01 level	Correlation is significant at 0.05 level
1–0.25	Pb–Mn–Co–Zn	Ti–Mn
0.25–0.05	Cr–Cu–Ni–Co; Zn–Cu–Co; Pb–Co–Ti	
0.05–0.01	Cu–Cr–Pb–Ni–Co; Zn–Co–Ni–Pb–Cu	
0.01–0.005	Cu–Cr–Pb–Ni–Co–Zn	Zn–Co–Ni
0.005–0.001	Ni–Co; Ni–Cr	Cu–Co
<0.001	Mn–Zn; Mn–Co	Pb–Co; Pb–Cu

cases) was found in the clay fraction. This can be explained by element sorption on clay minerals and organic matter [Titova et al, 1996]. Ni had either the maximum or second to maximum concentration in sand fraction (1–0,25 mm) depending on the genetic horizon. The minimum load of Fe, Mn, Co, Cu, and Ni was found in the coarse silt fraction, which can be a result of eolian origin of this fraction and/or epigenetic transformation during pedogenesis. The concentration of metals in a particular size fraction was defined by a complex of factors: element chemical properties, soil type and genesis of a soil horizon, as well as the position in the catena.

Correlation analysis has shown that the Co, Fe, Cr, Ni, and Cu concentrations in the bulk samples were linearly dependent on the clay fraction content, whereas Mn, Zn, and Pb were connected with the amount of the silt fraction. The Cr and Pb concentrations were controlled mainly by the amount of the sand fraction in the soil samples.

Statistical treatment of the particle size fraction subpopulations allowed us to identify the interrelated element groups typical of specific size fractions. They are listed in Table 2.

The results of the granulometric analysis and the analysis of fractionated top soil material for the HMs contents indicated that there are some catenary patterns in the distribution of the size fractions and associated metals. The highest amounts of sand fractions were observed in subordinate sections of the catenas. This corresponds to the textural characteristics of parent material. At these positions, it is represented by sandy moraine material (catena 2) and glaciofluvial sands (catena 1). The patterns of the silt and clay fraction distribution along the slopes can be explained by the intensity of erosion–accumulation processes and, therefore, be attributed to slope morphology.

Comparison of the catenary distribution of the HMs in the particle size fractions with those in the bulk soil samples based on the analysis of L-coefficients has shown that the distribution of the HMs in the particle size fractions was less uniform than in the bulk soil material and the contrast between the dispersion and accumulation patterns in the particle size fractions was more pronounced (L coefficients ranged from 0,03–7,0). The patterns of the HMs distribution in the particle size fractions were defined by the origin of a particular size fraction and by its transformation during pedogenesis. ■

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NUMERICAL MODELING OF THE FIELDS OF POLYCHLORINATED BIPHENYLS IN THE BLACK SEA

ABSTRACT. A mathematical three-dimensional model was developed by combining a physically complete block of circulation with moduli of transport and transformation of detritus and polychlorinated biphenyls (PCBs). This z-coordinate model has a horizontal resolution of 5×5 km, 45 vertical levels, and a step of 5 minutes. The model considers gravitational sedimentation and decomposition of detritus, as well as its deposition and erosion on the bottom. To calculate the transport and transformation of PCBs in the Sea, the model uses three state variables: the concentration of PCBs in solution, in detritus, and in the upper layer of sediment. It also considers sorption, desorption, and reversible flows of PCBs at the bottom.

A 20-day model calculation was performed to simulate a potential accidental release of PCBs in the area of the Danube Delta in spring. The PCBs advection flows dominated and were comparable to the adsorption/desorption flows, while the

diffusion fluxes were infinitesimal. Up to 20% of discharged PCBs were adsorbed by detritus in the first two days after the accident. There was a gradual accumulation of PCBs on the bottom; 16 days after the accident, 18% of the PCBs were bound to the sediments. The PCBs transport on detritus serves as a natural buffer mechanism that weakens the spread of PCBs in the sea. The paper analyzes the dynamics of PCB fields formed as a result of the application of an artificial active sorbent to minimize adverse effects on the ecosystem. An end-user oriented software application was developed; it allows forecasting the dynamics of potential releases of PCBs and planning counter-measures. A user-friendly interface allows tracking the field, visualizing the distribution of PCBs in the water column and sediments, and displaying the balance between dissolved and suspended phases.

KEY WORDS: multidisciplinary model, PCB transport, adsorption, desorption, sediments.

INTRODUCTION

Ensuring the safety of the environment requires other measures besides a timely cleanup of hazardous pollutants. A significant reduction of environmental risks has been achieved with the introduction of low-waste technology. However, predicting impact of accidental releases on the existing ecosystem is also very important. Finding solution to these problems is particularly relevant in areas of high population density, regions of active exploitation of marine resources, and recreational areas.

The urgent need to address the problems of ecological and analytical monitoring calls for research on transport and transformation of anthropogenic persistent organic pollutants that, even in low concentrations, adversely affect marine ecosystems. PCBs, some of the most common highly toxic synthetic chemicals, belong to the class of aromatic compounds consisting of two benzene rings connected by the internuclear **C–C** bond (Fig. 1). There, the hydrogen atoms are substituted with the chlorine atoms (1–10) in the ortho-, meta-, or para-positions. Theoretically, there may be 209 PCB congeners with a general formula

$S_{12}N_{10-n}Cl_n$, where $n = 1 - 10$. About a hundred of individual congeners have been detected in the marine environment in real conditions. These compounds have a number of specific features: the global prevalence; extreme resistance to physical, chemical, and biological transformations; bioaccumulation associated with low and high solubility in water and lipids, respectively; and toxicity to living organisms even at low concentrations. Mass production of PCBs occurred in 1929–1986 and then their commercial production was terminated. During this time, the world produced ~2 million tons of PCBs. Such widespread use of PCBs was due to a number of their unique physical and chemical properties: exceptional thermal, physical, and electrical insulating properties; thermal stability; inertness to acids and alkalis; flame resistance; good solubility in fats, oils, and organic solvents; and excellent adhesion. This determined their wide application as hydraulic fluids; coolants and refrigerants; lubricants; components of paints, varnishes, and adhesives; plasticizers and fillers in plastics and elastomers; flame retardants; and solvents dielectrics in transformers and capacitors.

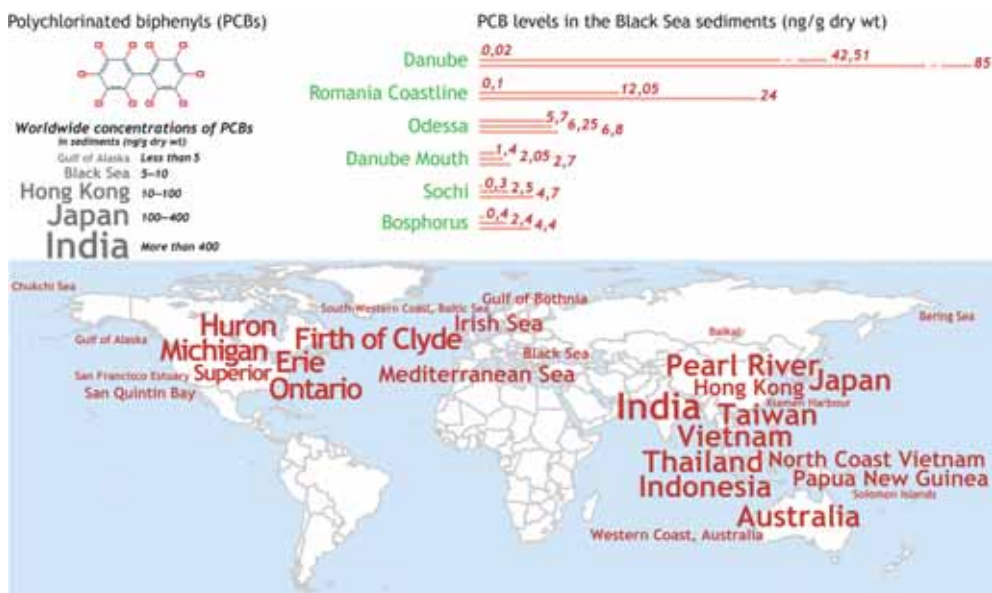


Fig. 1. Global distribution of PCBs

PCBs enter the ocean with river flow, precipitation, and technogenic discharge. The most important physical mechanisms of transport of PCBs in the sea are the advection and turbulent diffusion. The main sources of re-contamination of seawater are the sediments of the coastal and offshore areas of the oceans. It has been estimated [Jonsson, Carman, 2000] that removal of PCBs from the environment would take more than 100 years with a strict prohibition on production.

Experimental data [Orlova, 1994; Maldonado, Bayona, et al., 1999; Zherko, Egorov, et al., 2000; Fillmann, Readman, et al., 2002; Bakan, Ariman, 2004] show a significant PCB pollution of the Black Sea accompanied by intense accumulation of PCBs in biota [Tanabe, Madhusree, et al., 1997]. The map shown in Fig. 1 was compiled after [Burns, Villeneuve, 1983; Fillmann, Readman, et al., 2002; Bakan, Ariman, 2004; Dove, Hill, 2008] to demonstrate the role of the Black Sea sediments in the global distribution of PCBs.

The degree of PCB contamination of the sediments of the Black Sea and of its north-western shelf is between the relatively clean sediments of the Baltic Sea and the highly contaminated sediments of the basins of India and South-East Asia, where in the 1960s, PCB defoliants ("*Agent Orange*") were actively used [Dioxins and Health, 1994] and now there is rapid industrial development. The spatial distribution of PCBs in the sediments of the Black Sea (Fig. 1) is characterized by great variability. It shows a high degree of contamination of the sediments of the River Danube, the Romanian coast, and the Gulf of Odessa, which monotonically decreases to the coast of Turkey.

Mathematical modeling is one of the most effective methods for studying processes of PCBs transport in the natural environment. Exceptional capacity for PCB adsorption to organic carbon-rich particles, as well as the complex interaction of the processes of accumulation and release at the bottom, makes it impossible to model PCBs as

conservative tracers. Despite a fairly large number of laboratory studies and a steadily growing volume of field measurements so far there has not been a comprehensive model that adequately reproduces the spatial and temporal evolution of the PCB fields in the Black Sea. The specifics of our study is a comprehensive consideration of the dynamics of the three-dimensional flow fields and turbulent diffusion with adsorption and desorption of PCBs on detritus particles (suspended fraction of dead organic matter) as a natural sorbent of PCBs. Interaction between PCBs and sediment is also considered in the model. Development of advanced systems for forecasting the state of the marine environment and the consequences of accidental releases of PCBs aimed at scientific support of management decisions to minimize environmental risks is possible only within the framework of the above-described multi-disciplinary approach.

DESCRIPTION OF THE MODEL

A mathematical model [Lyubartseva, Ivanov, et al., 2012] was used to calculate the three-dimensional fields of PCBs in the north-western shelf of the Black Sea. The Black Sea is a deep (~2 km) semi-closed elliptical basin (Fig. 2) with the zonal and meridional length of 1000 km and 400 km, respectively. Hydrological structure of the Black Sea is mainly determined by freshwater runoff of the major European rivers: the River Danube, the River Dnepr, and water exchange through the Bosphorus and Kerch straits. Limited by the isobath of 200 m, the north-western shelf occupies 16% of the sea water and accounts for 0,7% of its volume [Ivanov, Belokopytov, 2011].

The model is built on the assumption (Fig. 3) that the distribution of PCBs in sea is determined by transport mechanisms: advection, turbulent diffusion, and gravity sedimentation of mono-disperse detritus and of PCBs on detritus. In the water column, PCBs is adsorbed on detritus particles to certain saturation. Then, the reverse process (desorption) begins, etc. On the bottom, diffusive exchange of dissolved PCBs with

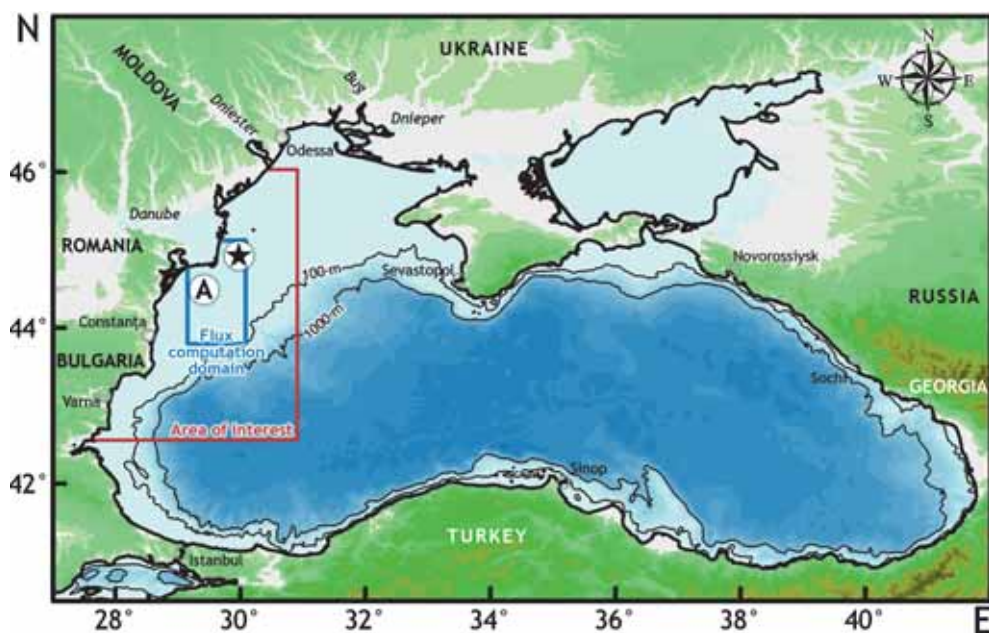


Fig. 2. The Black Sea. The star indicates the PCBs spill point used in the simulation.
The obtained Hovmöller diagrams relate to Station A

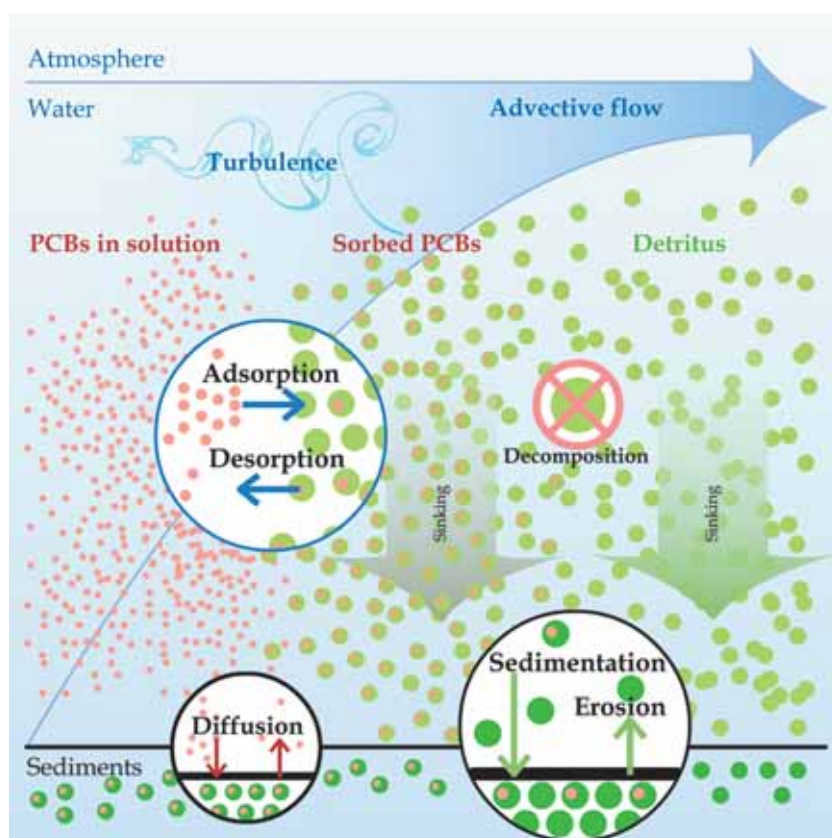


Fig. 3. Schematic representation of the modeled processes

the upper layer of the sediments takes place. The bottom exchange between detritus and PCBs on detritus is regulated by the balance of sedimentation and erosion flows. The decomposition of detritus is the resulting effect of its microbiological degradation, hydrolysis, and transition of the particles to a different size class.

The mathematical model consists of three blocks. In the hydrodynamic block, three-dimensional velocity fields of currents, temperature, and salinity of sea are calculated. These data are used in the detritus transfer and transformation block. The three-dimensional fields of velocity of currents, temperature, salinity, and concentrations of detritus are the input parameters of the PCBs transfer block, where PCB concentration in the solution, the concentration of PCBs on detritus particles, and the concentration of PCBs in the upper layer of sediments are calculated.

The hydrodynamic block utilizes a three-dimensional numerical z -coordinate model [Demyshev, Korotaev, 1992]. This model was developed in the Marine Hydrophysical Institute of the NAS and is used to solve problems associated with operational forecasts of the Black Sea; from the moment of its creation, it has been constantly improved. The model is based on a full set of nonlinear equations of motion and transfer of heat and salt in the Boussinesq approximation, hydrostatics, and incompressibility of seawater.

On the surface, daily fields of tangential friction stress of wind were assigned. The data array was obtained by averaging the 1988–1998 data derived from the surface pressure distribution, in 6-hrs increments. Daily fluxes of heat, precipitation, and evaporation [Belokopytov, 2004] were obtained through actual measurements and were assimilated according to the algorithm [Knysh, Demyshev, et. al., 2002]. On the bottom and solid sidewalls, the impermeability condition for the normal component of velocity and for adhesion for

the tangential component; the absence of heat and salt flows were assumed. At the liquid boundary, the Dirichlet condition at the inflow was assigned; the fluxes of pulse, heat, and salt were set for the outflow. The turbulent exchange of pulse and turbulent horizontal diffusion were specified as biharmonic operators. Parameterization was used as the vertical turbulent closure [Pacanowski, Philander, 1981].

In the detritus transfer block, the three-dimensional non-stationary fields of detritus concentration were calculated by the differential equation of the advection – diffusion – reaction type [Bagaiev, 2010]. The model takes into account gravitational sedimentation and decomposition of detritus. On the surface, the natural flow of detritus formed from decomposition of phytoplankton was assumed [Ivanov, Lyubartseva et. al., 1999]. On the bottom, the conditions of sedimentation and erosion that depend on the bottom shear stress were assigned [Ivanov, Fomin, 2008]. On the lateral boundaries, the absence of detritus flows was assumed.

The PCBs transfer block was based on the three-dimensional equations of the advection – diffusion – reaction type that describe the PCBs concentration in solution, in detritus, and in the upper layer of sediments [Ivanov, Bagaiev, et. al. 2012]. The processes of adsorption and desorption of PCBs deposited on detritus particles were accounted for according to [Margvelashvili, 1999]. On the surface, the absence of the PCBs flow was assumed. On the bottom, the balance conditions of exchange were assumed: diffusion exchange of the soluble component plus the exchange of the PCB-contaminated particles considering their sedimentation and erosion. On the solid lateral boundaries, the condition of the PCBs flow was assigned. On the lateral liquid-solid boundaries, the PCBs flow was assumed, imitating their entry into the sea from the rivers. The initial conditions assume the infinitesimal background concentrations of all state variables.

Model equations were integrated numerically on a uniform horizontal grid [Lebedev, 1964] with a resolution of 5×5 km, by 45 unevenly distributed horizons with a 5-minute time step.

MODELING THE SCENARIO OF A POTENTIAL ACCIDENTAL SPILL OF PCBs FROM THE DANUBE MOUTH

The developed model was used to calculate the three-dimensional fields of PCBs, formed as a result of an instantaneous emergency discharge of 4 kg of PCBs from the Danube St. George Girle in early spring. The northwestern shelf of the Black Sea during this period has high influx of detritus following the blooming of cold-resistant phytoplankton. It was expected that in these conditions, the process of adsorption and desorption of PCBs on detritus will reach its maximal intensity. Besides, this season has a relatively high flow velocity at the bottom, and it is necessary to examine sediment disturbance in the formation of secondary contamination of PCBs in the water column.

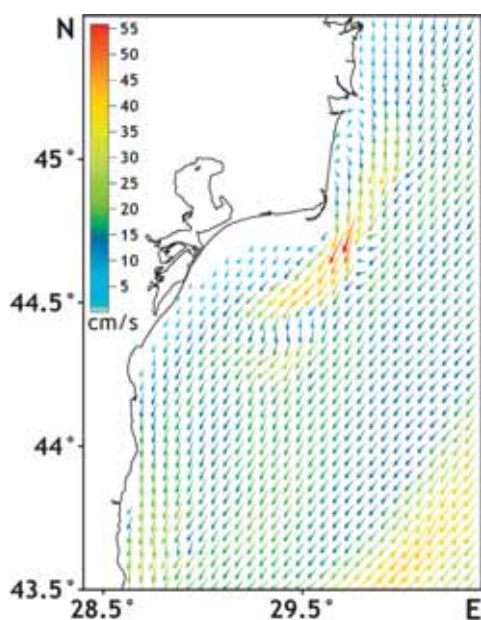


Fig. 4. Spatial distribution of horizontal currents (cm/s) at a depth of 3 m in 10 days after the accident.
The results of simulation

The dynamic problem of the PCBs field transport was solved using a 20-day interval.

Due to the prevalence of the north and northeastern winds typical for this season, with speeds of up to 10–15 m/s, the alongshore current, extending in the southwestern direction, formed in the computational domain (Fig. 4). It had the average speed of 20 cm/s. The flow velocity decreased on approaching the shore. The vertical velocity field had a complex structure with a pronounced downwelling and many local areas of sinking water. In the field of surface salinity, there formed a distinct frontal zone with a gradient of 1 PSU/10 km (Practical Salinity Units) due to the freshening influence of rivers.

On the 3rd day after the accident, the PCB and detritus fields at the depth of 3 m were carried to the area of Tulcea (Romania). At a 30 m depth, the field moved slower; there, dissolved PCBs were also adsorbed on detritus. Detritus and PCBs on detritus formed lenses in the bottom layers due to sediment detachment at the water-sediment boundary. Calculations have shown that the incidence of detritus and PCBs in the open sea was limited to a 75 m isobath. In 10 days after the accident (Fig. 5), the considerably diluted pollution fields reached Constanta (Romania). The southern vanguard part of the frontal zone reached Cape Kaliakra (Bulgaria). The boundaries of the fields were somewhat dissolving by diffusion. Analysis of the dynamics of the PCBs concentration fields in the upper layer of the sediments showed that the area was dominated by the classification types of sediments either transporting or accumulating PCB [Jonsson, Gustaffson, 2003]. The sediments of the transporting type, which not only adsorb PCBs, but also release them during detachment, are found near Cape Kaliakra. According to [Panin, Jipa, 1998], this area is under the direct influence of the Danube origin sediment flows and is the most dynamic and active because it comes close to the main current of the Black Sea.

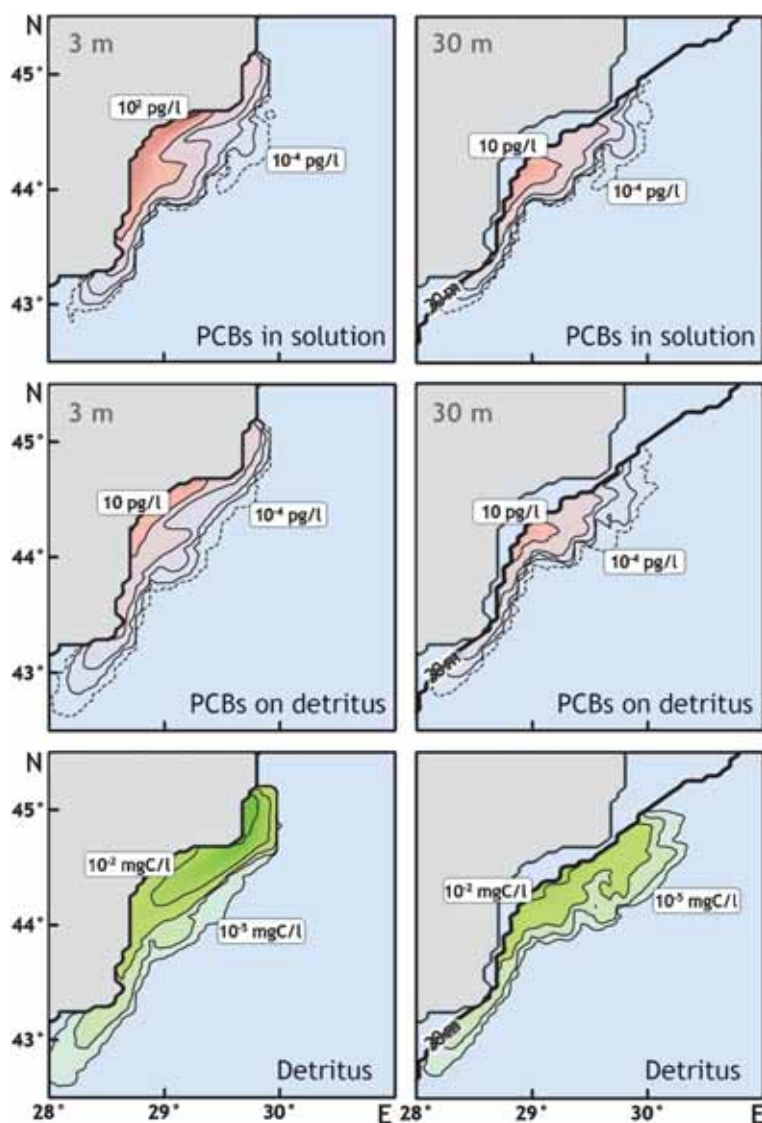


Fig. 5. Spatial distributions of the concentration of PCBs in solution (upper panels); PCBs on detritus (middle panels); detritus (lower panels) at a depth of 3 m (left) and 30 m (right) in 10 days after the accident. The results of simulation

The evolution of the vertical profiles of suspended and dissolved matter at Station A was investigated with the Hovmöller diagrams (Fig. 6). Fig. 6 (A) shows that the center of the dissolved PCBs field reaches the Station in 4 days after the accident. The maximal concentration of more than 30 pg/l is located at a depth of 26 m. The intensive adsorption on settling detritus begins. The concentration of PCBs in detritus in the center of pollution reaches 14 pg/l (Fig. 6 (B)). The

distribution of detritus is patchy (Fig. 6 (C)), which is typical for marine ecosystems. The concentration of detritus peaked at 0,01 mg C/l at the same depth (Fig. 6 (C)). Contaminated detritus was settling quickly on the bottom, where it was gradually building up (Fig. 6 (E)). In 4 days after the accident, the accumulation of PCBs in the sediments was maximal. It is evident that the sediments at Station A belong to the PCB accumulation type. Remaining in water detritus became saturated with PCBs

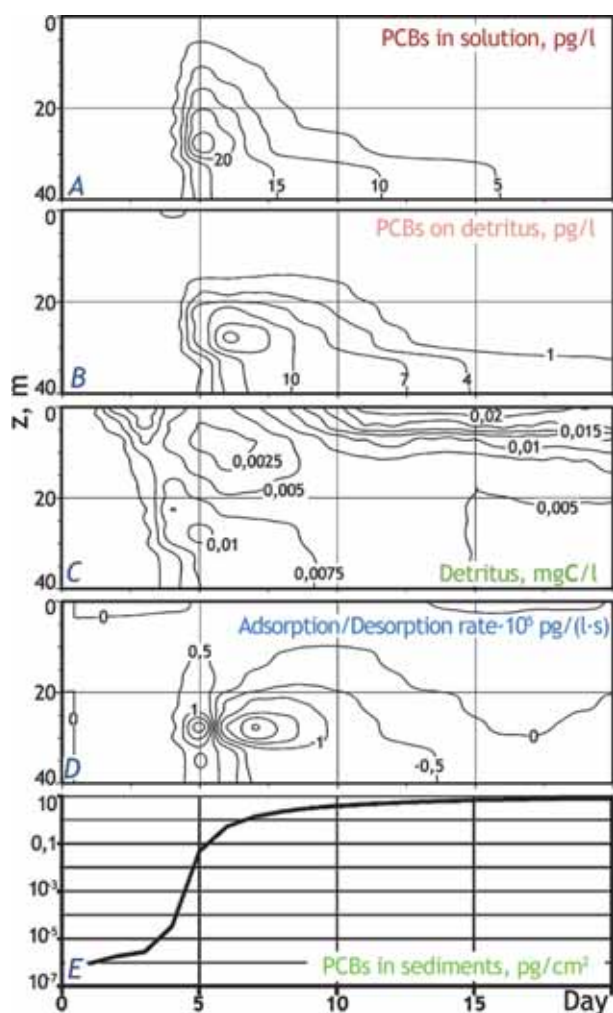


Fig. 6. The Hovmöller diagrams for Station A. (A) concentration of the PCBs in solution; (B) of the PCBs on detritus; (C) detritus concentration; (D) adsorption/desorption rate; (E) the PCB concentration in the top layer of sediments. The results of simulation

and, in 6 days after the accident, the reverse process of desorption took place. The chart (Fig. 6 [D]) shows the distribution of the rate of adsorption (positive values) and desorption (negative values). Change in the sign of this value appears as a pronounced dipole at a depth of 26 m. The resulting dipole asymmetry is caused by uneven distribution of detritus in the water column. The calculations have shown that the dissolved PCBs disappeared at this Station 4 days earlier than the PCB-contaminated detritus.

The budget of PCBs (Fig. 7) illustrates the redistribution of the PCBs that

have entered after the accident within the entire computational domain. Adsorption dominated during the first two days after the accident, which led to a 20% reduction in the mass of the dissolved PCBs. Desorption began 2 days after the accident. There was a gradual accumulation of the PCBs on the bottom. It has been demonstrated that 16 days after the accident, sediments bounded 18% of the PCBs. It can be concluded that the sinking particles of detritus, as a natural sorbent PCB, form a natural buffer system, which speeds up water purification and binding of PCBs in sediments.

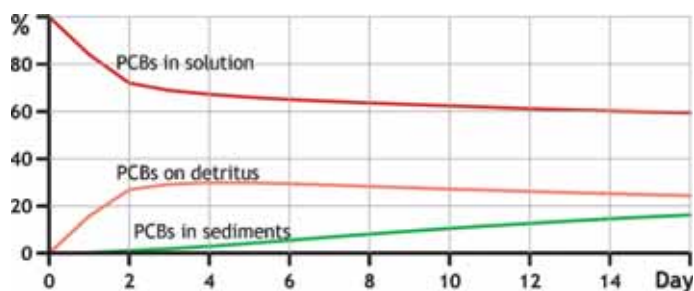


Fig. 7. The PCB budget on the Black Sea northwestern shelf. The results of simulation

To estimate the contribution of different physical mechanisms to the development of the three-dimensional fields of PCBs, the PCBs fluxes were calculated in the closed

three-dimensional region bounded by 44,2°–45,1°N and 29,2°–30,1°E, which corresponds to a rectangular area with dimensions of 100 km × 75 km (Fig. 2). The calculations have shown that advection transport and adsorption-desorption of physical and chemical fluxes dominate in this area (Fig. 8). The positive values for advection and diffusion correspond to the influx, while the negative ones – to the efflux. For adsorption, the positive flow means the “transfer” from the dissolved form to detritus. Among the advection flows, the flow through the western boundary dominated, with its maximum of 0,13 g/s on the 6th day after the accident. The adsorption and desorption flows had the following characteristics of the local extremes: $5,0 \times 10^{-2}$ g/s on the 6th day and $-1,5 \times 10^{-2}$ g/s on the 10th day. The horizontal turbulent diffusion ($\sim 10^{-18}$ – 10^{-13} g/s) appeared to be the weakest transport mechanism in the system.

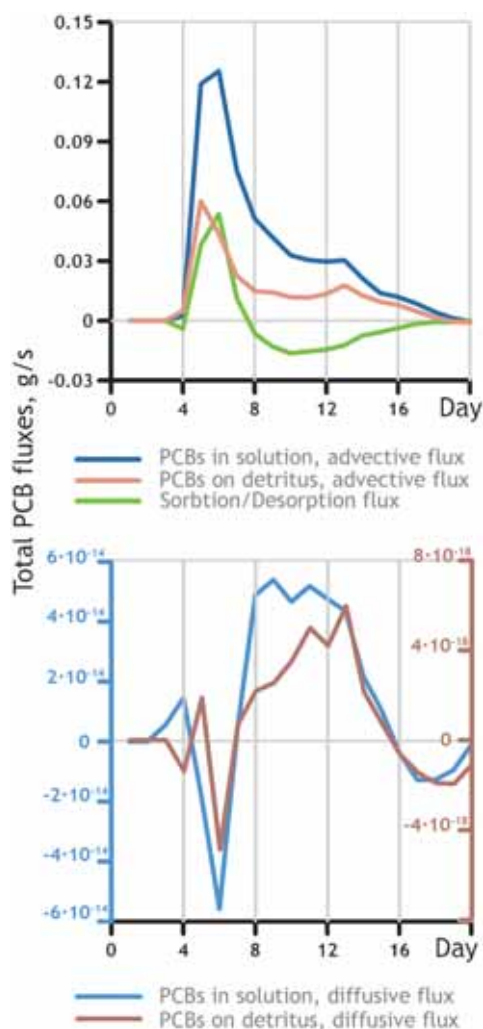


Fig. 8. The total PCB fluxes through the finite domain shown in Fig. 2. The results of simulation

EVALUATION OF EFFICIENCY OF AN ACTIVE SORBENT APPLIED TO CONTROL THE PCBs SPREAD

High sorption capacity of PCBs may be used in integrated post-emergency measures to reduce dispersion of PCBs in the marine environment. The model can evaluate the effectiveness of the use of active sorbents in combating the adverse effects of an accidental release.

For this, the master equations of the model were modified and supplemented with the equations of the advection-diffusion-reaction type for the concentrations of the active sorbent and of PCBs on it [Bagaiev, Lyubartseva, 2011]. Physical and chemical

characteristics close to real conditions were assigned [Delle Site, 2001] for the active sorbent. Using test-calculations, a close to optimal strategy of placing the sorbent in the sea was chosen.

A numerical experiment was realized in the following scenario. A hypothetical monitoring service detects an accidental release of PCBs, as described in the previous section. The calculation under the framework of the developed model forecasts the PCBs field trajectory. To minimize negative consequences of the accident, in 5 hours, 120 tons of the active sorbent with the sorption capacity threefold exceeding that of natural detritus were instantaneously dropped into 12 surface boxes located perpendicular to the mean vector of the field movement (Fig. 9).

The calculations have shown that the rate of gravitational sedimentation of the artificial sorbent was very important. If the rate is too high, the sorbent settles on the bottom much faster than the speed at which PCBs are adsorbed on its surface. If the rate of sedimentation is too low, the sorbent is removed from the field by strong surface currents before it gets saturated with PCBs. The sedimentation rate of detritus in the model was assumed to be 10^{-3} cm/s; the rate of sedimentation of the active sorbent was $5 \cdot 10^{-3}$ cm/s.

Fig. 9 shows the evolution of the field of dissolved PCBs at a depth of 3 m without the sorbent (left) and with its application (right). The PCB fields, in violet-blue colors, were delineated by a contour of a 3,10 pg/l concentration of dissolved PCBs. The field of the active sorbent is delineated by the green contour with the concentration of 1 pg/l. In the upper right frame, the black color indicates the line of the active

sorbent "injection." On the right series of frames, the sorbent field was drawn on the top of the PCBs field, because the distribution of the PCBs without and with the sorbent were practically identical. Subtle differences can be seen in the frames corresponding to the 8th day after the accident. The field of concentration of the active sorbent was deforming in the surface water layer due to the dynamically active flow of the alongshore current. By the 6th day, there was a disruption of the active sorbent concentration field. One part of it was carried away in the open sea and the other one was accumulating in the apex area of the coastal zone.

The efficiency of the active sorbent was controlled by the PCBs budget (Fig. 10). By

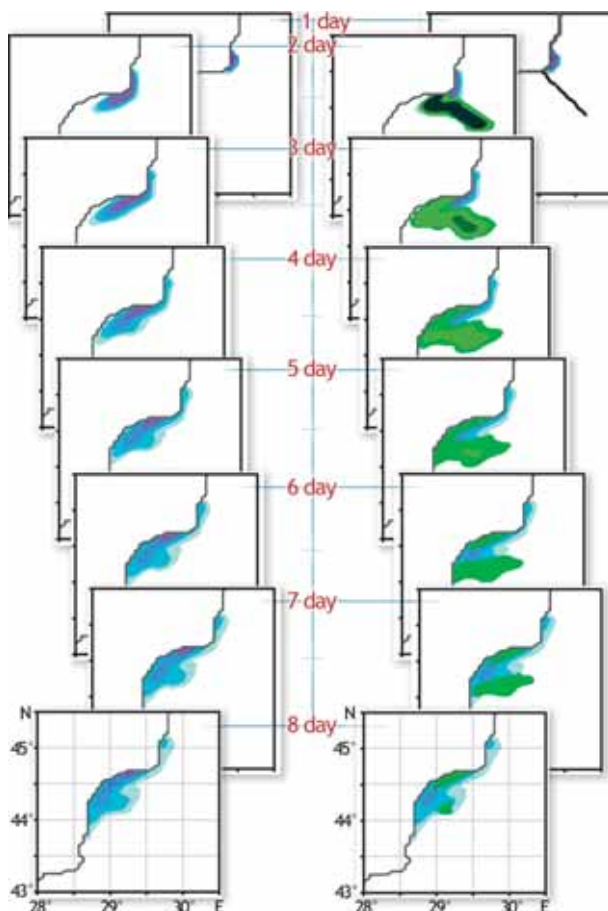


Fig. 9. The PCB-spill evolution at a depth of 3 m, without (left panel) and with (right panel) the active sorbent. The PCB concentration is in blue; the active sorbent concentration is in green. The results of simulation

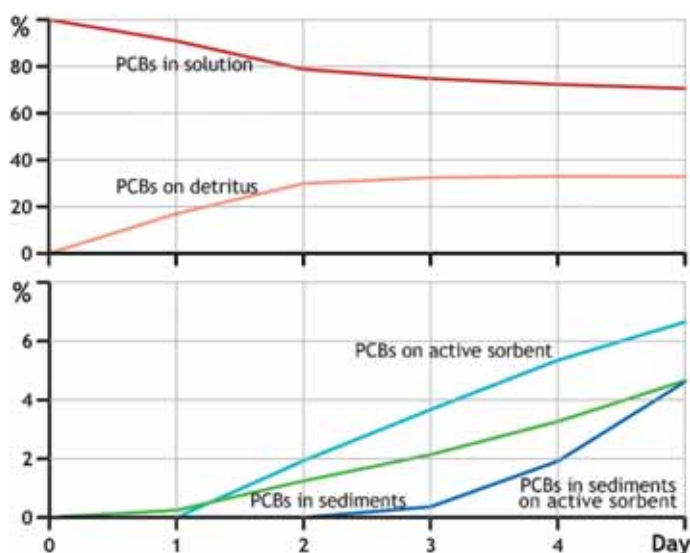


Fig. 10. The PCBs budget in the scenario with the active sorbent. The simulation results

the 5th day after the accident, about 30% of PCBs was adsorbed on detritus particles and only 6% of the PCBs was adsorbed by the active sorbent; 4% of the PCBs was adsorbed by the sediment. The mass of the PCBs adsorbed by the active sorbent was significantly lower than that of the PCBs adsorbed by detritus. However, the active sorbent accumulated PCBs much faster than the top layer of sediment. By the 5th day after the accident, the mass of the PCBs adsorbed by the active sorbent particles was equal to the mass of the PCBs adsorbed by the sediments. In general, it may be stated that the work of the active sorbent in the water column was ineffective because of a too short retaining time of the center of the PCBs contamination in the zone of active sorption. Detritus as a natural PCBs sorbent works much better due to the homogeneous distribution in the water column. Approximately half of the mass of the active sorbent is carried far away at sea, i.e., it is practically useless. The ratio of the areas of the contaminated bottom with and without the sorbent application is about 95%.

However, the numerical experiments showed that, on time scales exceeding 15 days, the active sorbent is more efficient in

the PCB containment in the top layer of the sediments compared to detritus. It means that the sorbent should be introduced directly into the upper layer of sediments of the apex near shore areas where it would, due to its high absorptions capacity, actively adsorb contaminants during time-frames of about a month and would block potential re-contamination of the water column.

DEVELOPMENT OF THE END-USER APPLICATION

For efficient decision-making based on the model presented above, an application module with a remote web interface is being developed. A user-friendly system interface (Fig. 11) includes input fields for the date and time of an accident, its duration, the rate of contamination influx, and the coordinates of the discharge. A database of physical-chemical parameters of different congeners and PCB-containing mixtures is being compiled. In the future, this knowledge-based system will allow an end-user to calculate the trajectory of contamination fields, visualize the three-dimensional field of PCBs in solution and on detritus, map the contamination on the bottom, and plan countermeasures.

PCB spill request form

Spill date&time: 04 Feb 2006 10:00

Spill duration (hours): 1

Spill rate (g per hour): 4000

Congener type: 101

Initial latitude (°N): 44.47

Initial longitude (°E): 29.49

Output parameters:

Simulation lasting (hours): 200

Time interval (LGRD, hours): 24

Depth interval (LSTEP, layers): 2

Submit

Fig. 11. A web interface for end-users

CONCLUSIONS

1. A 3D interdisciplinary model of the PCBs dynamics has been developed; the model considers physical transport mechanisms, advection and turbulent diffusion, as well as physical and chemical processes of adsorption and desorption on detritus. The model takes into account exchange processes at the boundary water – bottom sediments. The model combined three units: (1) thermo-hydrodynamic, (2) transport and transformation of detritus as a natural PCB sorbent, and (3) PCB transport.

2. The assessment for a 20-day period of the contamination fields after a potential accidental discharge in the Danube River Delta has been conducted. The advection transport of PCBs by the near shore jet current was the dominating mechanism. The adsorption and desorption flows on detritus were comparable with the advection flow. During the first 2 days after the accident, 20% of the mass of PCBs was adsorbed on

detritus, indicating the existence of a natural buffer system that speeds up the purification of water and binding of PCBs by bottom sediments.

3. The model allowed assessment of the efficiency of the use of an active sorbent for mitigating negative impacts of an accident. It has been demonstrated that placing the active sorbent into the water column of this dynamically active sea area is inefficient. It is feasible to use it in the top layer of the sediments of the apex areas where it works effectively on time scales of the order of months.

4. To support management decisions using the model, an application module with a remote web interface is in the process of development. In the future, it would allow estimating the trajectory of PCB-contamination fields, visualizing the PCBs fields in solution and on detritus, mapping bottom contamination, and planning environmental protection activities. ■

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A HISTORICAL OUTLINE OF RADIONUCLIDE CONTAMINATION OF THE YENISEY FLOODPLAIN BASED ON LANDSCAPE AND RADIOMETRIC SURVEY

ABSTRACT. Distribution of technogenic radionuclides discharged by the Krasnoyarsk Mining and Chemical Combine (KMCC, Zheleznogorsk) in the period from 1958 to 1992 has been studied in floodplain landscapes of the Yenisey river. After shutting down the direct-flow reactors the radioactive contamination of the Yenisey river became dozen times lower. Performed landscape and radiometric studies revealed factors responsible for radionuclide differentiation and the character of radionuclide distribution within two landscape segments of the Yenisey river floodplain. The first segment characterized the impact zone from 16 km to 20 downstream the discharge, the second one was studied in the remote zone as far as 2000 km down the river. Artificial radionuclide contamination was most intensive in the 60-ies of the past century when it reached the Kara Sea. Traces of that contamination were registered in soils of both sites at the depth of 20–50 cm.

KEY WORDS: radionuclides, landscape, floodplain, Yenisey River, Krasnoyarsk MCC.

INTRODUCTION

In the period from 1958 to 1992 an operation of the Krasnoyarsk Mining and Chemical Combine (KMCC) located in the

town of Zheleznogorsk 40 km downstream the city of Krasnoyarsk led to radionuclide contamination of the water and bottom and floodplain sediments of the Yenisey river mainly with ^{137}Cs , ^{60}Co , ^{152}Eu , ^{154}Eu over long distances downstream the discharge of radioactive elements [Vakulovsky et. al., 1995]. After shutting down of the two direct-flow reactors in 1992 the amount of radionuclide discharge to the Yenisey river dropped dozen times and radioecological situation improved.

The systematic radioecological studies of the Yenisey river which included the analysis of radionuclide contamination of water, bottom sediments and the coastal floodplain date back to the year of 1972 [Vakulovsky et. al., 2008]. Then for the first time they discovered radioisotopes of the reactor origin (^{65}Zn и ^{137}Cs) in the bottom sediments of the Yenisey mouth. The studies performed by SPA "Typhoon" within the large river segment stretching from KMCC to port Dudinka at the beginning of the Yenisey delta revealed considerable radionuclide contamination of the floodplain soils [Vakulovsky, 2008]. The levels of ^{137}Cs and ^{60}Co 48 km downstream the discharge equaled to 230 kBq/m² and 47 kBq/m², and 409 km downstream – 34 kBq/m² and 19 kBq/m² correspondingly.

As far as 1655 km away from the discharge the contamination by ^{137}Cs and ^{60}Co dropped sharply down to 21 kBq/m² and 0,37 kBq/m². One should note that at the beginning of 70-ies the global level of ^{137}Cs was 2,5 kBq/m² [Kvasnikova et. al., 2000].

However these studies were kept secret at that time and known only to a narrow group of specialists. The results of the further expeditions organized by SPA "Typhoon" in 70-ies were unknown until the beginning of 90-ies when after the Chernobyl accident the data on radionuclide contamination of the area of the former USSR were declassified and the independent radioecological studies of the Yenisey floodplain became available. Since that time there began massive studies of distribution of technogenic radionuclides in the Yenisey basin.

STUDIED AREA, MATERIALS AND METHODS

The first scope of data on radioecological situation in the Yenisey river flood plain based on field sampling was published in 90-ies of the last century [Kuznetsov et. al., 1994; 1999; Vakulovski et. al., 1995; Nosov et. al., 1993; Nosov, 1996; Linnik et. al., 2000; Sukhorukov et. al., 2004]. A review of some part of these data was done in the frame of the projects launched by Green Cross Russia. The main goal of these projects was the data organization as a geo-information system (GIS) covering all the available sources of information on radionuclide contamination of the environment in areas of location of the nuclear-fuel operating plants. The Yenisey floodplain section from the KMCC down to practically its lower reaches and discharge to the Kara Sea was among the objects under [Linnik et. al., 2001].

The map of radionuclide contamination of the Yenisey floodplain was constructed during preliminary works on a set of maps for the Atlas of radionuclide contamination of Russia in areas of the plants producing weapon plutonium [Izrael et. al., 2000]. In framework of the program on mapping

the areas with technogenic radionuclide contamination an air-gamma survey of the Yenisey floodplain was carried out in 1993 that revealed the longest in the FSU belt of ^{137}Cs contamination stretching for 2000 km from KMCC to port Dudinka [Kvasnikova et. al., 2000].

The second stage of radioecological studies in the Yenisey basin started in 90-ies in frame of series of international and regional projects including complex expeditions.

The presented work is based on materials obtained during field work supported by two international COPERNICUS projects: the STREAM (near impact zone of KMCC) and ESTABLISH (the distant zone) performed in the years of 2000, and 2001–2002, field studies in the upper delta of Yenisey were organized by the Vernadsky Institute of the Russian Academy of Sciences in cooperation with the Moscow State University. The data on radionuclide contamination included both the published and archival materials.

The main goal of the work was to analyze the landscape structure, relief, the soil and vegetation cover, composition of the river sediments and to reveal landscape peculiarities of distribution of ^{137}Cs , ^{60}Co , $^{152,154}\text{Eu}$ in the impact area of the KMCC. The most contaminated low-and medium-level floodplain of the river was the first object to study. Plots located on terraces or the adjacent watersheds were used for local data on global technogenic radionuclide fallout.

To determine contamination density and radionuclide distribution in soil profiles standard soil sampling in increments was applied with due regard to river sediment lithology. In the near KMCC impact zone the radioecological studies included field gamma-spectrometry measurements with the help of collimated detector CORAD. To measure depth distribution in floodplain soils in field conditions a radiometer with dip detector was used. The main principles of evaluation of technogenic radionuclide

concentration with the help of the CORAD device applied to landscape-radiation investigation of the Yenisey floodplain were published in [Linnik et. al., 2005; 2006].

Radiometric measurements enabled to optimize the sampling mode and to select the most representative plots. However, this approach appeared to be applicable in case of contamination level exceeding 10 kBq/m^2 . At the lower level the error of detection considerably increased and in the lower Yenisey area the sampling was based on landscape geochemical structure and the suggested conditions of technogenic radionuclide deposition [Korobova et al, 2002, 2007, 2009].

RESULTS

Peculiarities of the Yenisey hydrological regime in the period of radionuclide contamination

Radionuclide transport and concentration with the Yenisey waters depend in general upon its hydrological regime. The discharged radionuclides actively migrate with water masses contaminating bottom sediments and floodplain soils in the high water periods. The Yenisey water flow considerably increases after the river confluence with its right tributary – the Angara River. The mean annual discharge of the Yenisey River equals to $2864 \text{ m}^3/\text{s}$ (hydrological station Bazaikha), while that of the Angara river amounts to $4518 \text{ m}^3/\text{s}$ [Lammers and Shiklomanov, 2006]. As a result the concentration of radionuclides in the contaminated Yenisey waters considerably reduces after the confluence. The next significant dilution of the main stream water takes place after the confluence with the river of Podkamennaya Tunguska in the middle reaches of Yenisey. Here the annual Yenisey discharge reaches $10769 \text{ m}^3/\text{s}$ (gauge station Podkamennaya Tunguska). It continues to increase in the lower reaches up to $18395 \text{ m}^3/\text{s}$ (hydrological station at port Igarka). Such dilutions considerably lessen radionuclide concentration in river water.

The main radionuclide contamination of the Yenisey basin occurred in the years of 1966, 1972 and 1988 abound in water. The high water period of 1966 was maximum and the longest. The high-water events of 1972 and 1988 succeeded the construction of the Krasnoyarsk hydroelectric power station in 1970 which changed the Yenisey hydrological regime in such a way that since then the high floodplain within the river segment from KMCC down to the Yenisey confluence with the Angara river has never been flooded any more and the period of the middle floodplain flooding has shortened. However, deposition of sediments contaminated by radionuclides continued in the lower floodplain areas. The influence of the Krasnoyarsk HPP on the main stream water abundance in the middle Yenisey was leveled due to its tributaries. However the high water levels of 1972 and 1988 could be followed not only in the upper Yenisey section (Bazaikha) but in its middle part also (Podkamennaya Tunguska). This could have resulted in similar character of technogenic radionuclide distribution on different levels of the river floodplain landscapes. In the lower Yenisey reaches high water periods do not coincide with those registered at the two indicated gauge stations. For example, in August 1988 the Igarka station did not register high water in Yenisey unlike the upstream stations. Therefore one should not expect synchronized radionuclide deposition in the upper-middle and the lower Yenisey sections.

Analysis of the results of some previous studies concerning KMCC impact on the Yenisey floodplain contamination

The air-gamma survey of the Yenisey basin in 1993 has recorded radionuclide contamination of its floodplain section 1760 km long stretching from Zheleznogorsk to Dudinka along both its right and left bank zones (Fig. 1). The results of this air-gamma survey demonstrate the scale of contamination and some difference between the coastal zones: the mean and maximum ^{137}Cs contamination levels of the left bank

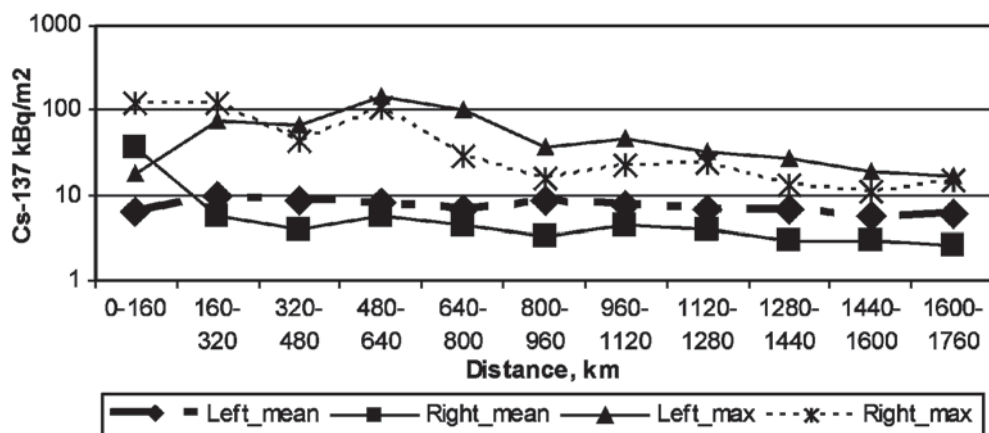


Fig. 1. Results of air-gamma survey of the Yenisey river floodplain performed in 1993
[Kvasnikova et. al., 2000].

Left_mean – mean values of ^{137}Cs activity (kBq/m^2) along the Yenisey left bank; **Right_mean** – the same for the right bank; **Left_max** – maximum values of ^{137}Cs activity (kBq/m^2) along the Yenisey left bank; **Right_max** – the same for the right bank

floodplain were noticeably higher than those of the right one except for the near impact zone within 160 km downstream the KMCC which is located on the right bank of the river. ^{137}Cs contamination considerably exceeded its global levels varying in the interval of 1,7–2,5 kBq/m^2 [Kvasnikova et. al., 2000; Sukhorukov et. al., 2004].

In the remote zone of Yenisey contamination the average value of ^{137}Cs activity varied from 2,9 kBq/m^2 to 6 kBq/m^2 with similar maximum values several times exceeding the global level. In the near zone maximum ^{137}Cs contamination of the left bank zone equaled to 18 kBq/m^2 , while on the right bank it reached 122 kBq/m^2 . The next zone with high ^{137}Cs contamination density was observed on the left bank 480–640 km and 640–800 km downstream, where the maximum values amounted to 144 kBq/m^2 and 100 kBq/m^2 correspondingly. The existence of high radioactive contamination of the middle section of the Yenisey basin falling downstream was found also by the other investigators. The measurements performed at two river stations located 166 km (the first one) and 784 km (the second one) downstream the KMCC by [Vakulovsky et. al., 2008] in summer period of 1979 showed the following levels for ^{152}Eu ^{137}Cs ,

^{60}Co : the 1st station – 6 Bq/m^3 , 8,7 Bq/m^3 and 10 Bq/m^3 ; the 2nd station – 2 Bq/m^3 , 2,4 Bq/m^3 and 4,1 Bq/m^3 . This means that as far as 784 km downstream the discharge point there was a 2–3-fold decrease of radioactivity of a set of radionuclides corresponding to the 2,9 increase of the total river discharge within this distance interval. A relatively high and variable portion of ^{152}Eu ^{137}Cs and ^{60}Co radioisotopes migrating in suspended particles (0,6, 0,5, 0,93 of total unit 166 km downstream and 0,8, 0,5 and 0,6 784 away correspondingly), led to different modes and levels of contamination of the floodplain soils by various radionuclides during deposition of the suspension.

High level of technogenic contamination of the bottom river sediments and the soils in the middle Yenisey segment before the reactors were shut down was also registered in 1991 by A. Nosov [Nosov et. al., 1993]. For example, the activity of ^{137}Cs and ^{60}Co measured by him in the Belij island 510 km downstream the discharge point reached 53–78 and 20–63 kBq/m^2 . In vertical soil profile two peaks corresponding to the soil surface and the depth interval of 30 to 40 cm were found, both being of practically similar activity. This is a cogent argumentation in favour of the two stages of the major

contamination of the Yenisey basin. The first peak dating back to 60-ies of the past century was marked by radionuclide contamination of the buried alluvial layers while the second one found in the surface soil layer was formed due to the contaminated high water in the year of 1988.

Results of the studies in the near KMCC impact zone

The near KMCC impact zone embraces the areas 16–20 km downstream the discharge point of technogenic radionuclides. The investigated part of the floodplain included the Island of Beriozovy measured with the help of radiometer CORAD along three landscape transects (BP-0, BP-1, BP-2), and a plot Balchug (BP-4) 20 km downstream the discharge point. Cross-section BP-0 was located at the head of the island. It started from the Balchug branch and crossed the low, low medium and high level floodplain (Fig. 2). One should note that at the mainstream side both the low and medium levels were practically absent and passed abruptly into the high floodplain. In general the same asymmetric morphological structure is typical for whole island of Beriozovy. Cross-sections BP-1 and BP-2 being 105 m and 160 m long started also at the Balchug flow parth, crossed the low and medium floodplain and reached the high level floodplain. Following the levels of radionuclide contamination measured along the BP-0 cross-section one could see their relation to peculiarities of morphology of the island floodplain (Fig. 2).

The Balchug floodplain massif had a more complicated landscape structure which was reflected in a larger variation of the inventory of technogenic radionuclides corresponding to its different landscape parts [Linnik et. al., 2005; Linnik, 2011]. Landscape complexes of the Balchug area were composed of the island part 350–400 m wide attached to the right bank of the Balchug branch. The coastal zone had a flat or wavy flat surface dissected by the narrow (10–20 m wide) flow paths which dried out when the current water level dropped below 1 m over the mean low water one. The length of Balchug cross-section equaled to 460 m and contained 48 measurement points. Statistical parameters of radionuclide distribution in the areas studied in the near impact zone are presented in Table 1.

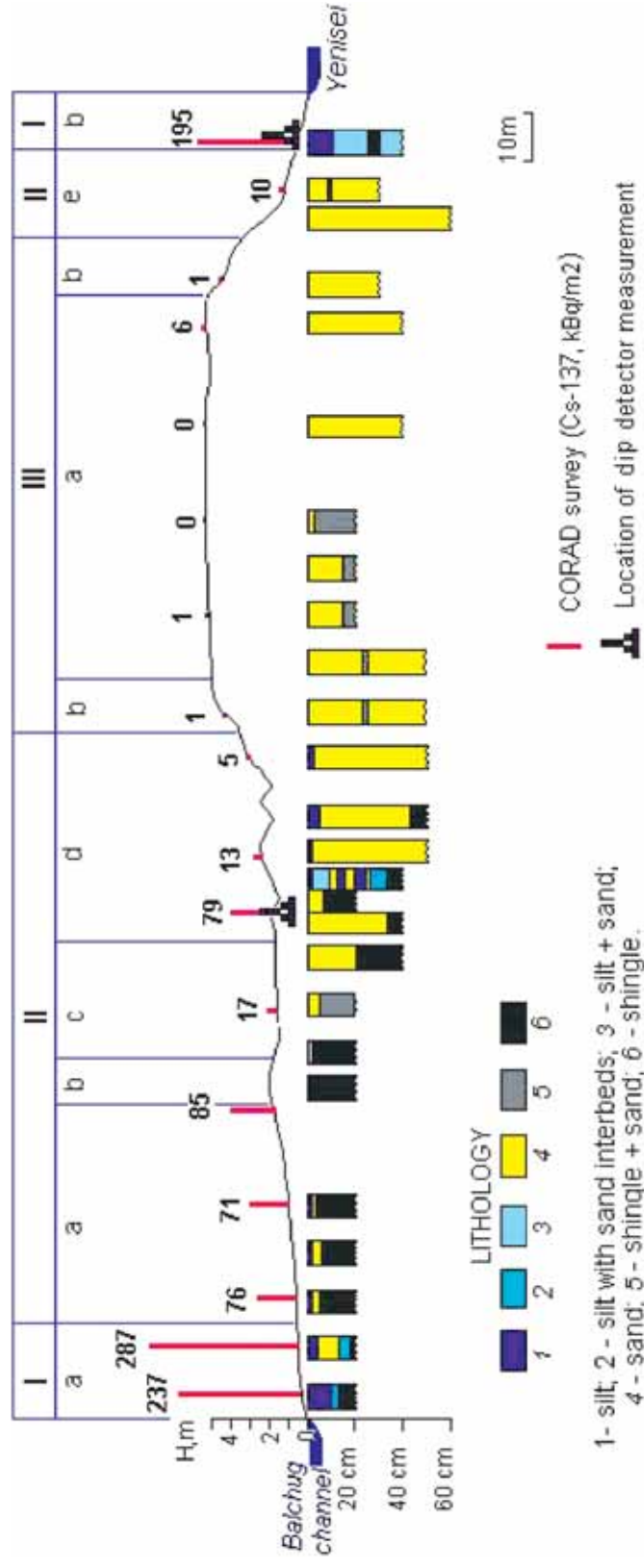
As the global ^{137}Cs contamination within the near KMCC impact zone equaled to $1,75 \text{ kBq/m}^2$ [Sukhorukov et. al., 2004] the data of Table 1 demonstrated that almost the whole area under study was subjected to radionuclide contamination. The exception stood for the plots located in the high level floodplain of the Beriozovy Island at the highest elevation levels (over 6 m of altitude), where the ^{137}Cs contamination density was somewhat lower than the global one or was not registered at all. In general this floodplain segment was characterized by very high differentiation of ^{137}Cs contamination density within small distances.

The revealed zones of maximum accumulation of ^{137}Cs (up to 1000 kBq/m^2) were located

Table 1. Field data on ^{137}Cs activity measured along cross-sections of the Yenisey floodplain in the KMCC near impact zone

Id	Distance from the discharge source (km)	Total number of measurement points	Maximum height* (cm)	^{137}Cs activity (kBq/m^2)			
				Mean	Min	Max	St.dev.
BP-0	96	16	616	81,8	1,5	287	103,6
BP-1	96	8	324	129,1	24	251,6	77,3
BP-2	97	25	650	182,4	19,2	663,4	158
BP-4	100	48	563	183	9,6	1002	175,8

* Relative to water level at the time of survey in August 2000 (for BP-0 – August 1999).

Fig. 2. ¹³⁷Cs distribution along the landscape cross-section BP-0 (the Beriozovy Island)

in the low floodplain composed of fine and small-grain sands with loamy interlayers at the bottom of the former flow paths now covered by a thin turf layer, and in depressions at the footslope of the middle-level floodplain where sandy-silt river load was deposited. The contamination density of ^{60}Co and $^{152,154}\text{Eu}$ in total reached the maximum value (190 kBq/m^2) also on the lower floodplain containing silt, peat and light loam deposits [Linnik et. al., 2005; Linnik, 2011].

The character of spatial distribution of radioactive contamination could be demonstrated by the measurements of 1999 performed along the landscape cross-section BP-0 located at the head of the Beriozovy Island (Fig. 2, [Linnik et. al., 2002]).

Landscape structure of this part of the Island Beriozovy included three elevation levels: the low, medium and high floodplain, which differed significantly in the density of ^{137}Cs contamination. Landscape cross-section BP-0 of the Beriozovy Island included 28 level and 16 field measurement points. At two locations (points #11 and #24) ^{137}Cs depth profile was measured with the help of the dip detector.

High water level (IIa is the basic floodplain surface, IIIb is the slope of the high bottom terrace) has been registered within the floodplain 4–5 m above the river water level. This section was formed by thick sandy series with particular horizons containing rare shingle and showed ^{137}Cs activity values below the sensitivity of the "CORAD" radio-spectrometer ($1\text{--}6 \text{ kBq/m}^2$). Almost all the ^{137}Cs contamination here was concentrated in the lower level locations with maximum silt deposition. According to the "CORAD" field measurements the density of ^{137}Cs contamination of the low floodplain (Ia) varied from 195 to 287 kBq/m^2 . Middle height floodplain level (Fig. 2, section II, a, b, c, d, e) was characterized by a more complicated composition of sediments that was reflected by variation of ^{137}Cs contamination density from 5 kBq/m^2 to 85 kBq/m^2 .

Basing on measurement data at point 24 where the ^{137}Cs contamination density amounted to 195 kBq/m^2 the soil depth profile was sampled for the further laboratory analysis. The two clear depth maximum values of activity were found. They were suggested to be related to different periods of increase of radioactivity in river water due to release of the radionuclide waste from

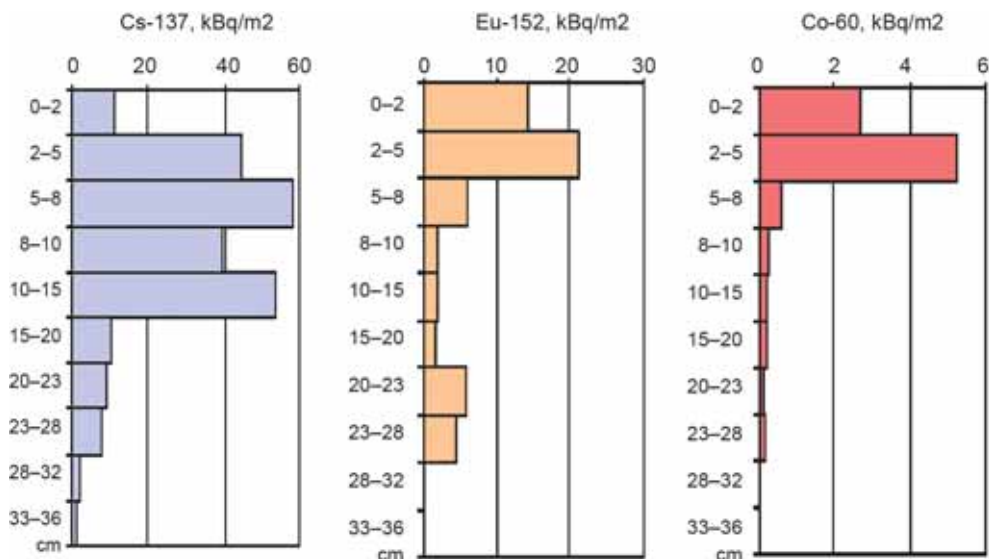


Fig. 3. Radionuclide distribution in the soil core MBP-1 (cross-section BP-4)

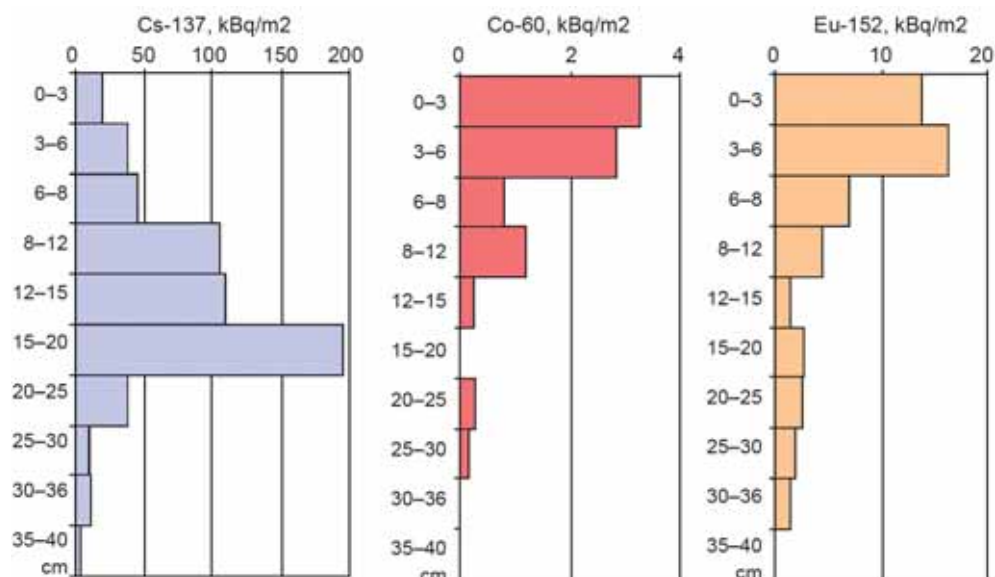


Fig. 4. Radionuclide distribution in the soil core MBP-2 (cross-section BP-4)

the Krasnoyarsk MCC. The first maximum of ^{137}Cs activity (630 Bq/kg) was found at the depth of 10–20 cm and corresponded to a sandy silt layer underlain by gley sand and silt, the second maximum activity (320 Bq/kg) was detected at the depth of 30–35 cm in the silty sand horizon. In the lower layers of the grey sand observed to 45 cm depth the activity dropped sharply to 23 Bq/kg.

The depth profile MBP-1 (Fig. 3) was located at the BP-4 cross-section of the Balchug massif and characterized the laminated alluvial sandy loam soil of the upper low-level hillock plot covered by the grazing meadow of forb-foxtail composition with birch and willow sprouts 2,13 m above the water mean level. The soddy silty sand at the top of the profile was succeeded by fine sands of laminated structure. There were two distinct peaks of radiocesium at the depth of 5–8 cm and 10–15 cm corresponding to the laminated sandy-loam horizons separated by a small radioactivity fall in the intermediate sandy layer. Both ^{152}Eu and ^{60}Co had maximum concentration in the top 2–6 cm layer showing fresh alluvium contamination at the indicated altitude.

Another depth profile at this cross section (MBP-2, Fig. 4) characterized the alluvial soddy sandy soil formed 3,19 m above the shoreline on top of the ridge of the medium-level floodplain under willow stand with bird-cherry trees and currant bushes. The soil core appeared to be contaminated by radiocesium twice as much. Maximum radiocesium inventory contained at the depth of 15–20 cm corresponded to the two thin humic gley loamy layers (Fig. 4). ^{60}Co concentration is half that being found in the soil profile MBP-1. This allowed suggesting the considerable earlier contamination of the ridge and its minor contamination during the later flooding processes since ^{60}Co and $^{152,154}\text{Eu}$ were found in the top layers.

High levels of ^{60}Co and $^{152,154}\text{Eu}$ activity in the surface soil layers supported the hypothesis of their possible contamination during high water in the year of 1988.

Results of the studies in the remote KMCC impact zone

Shown above the remote impact zone of KMCC stretched for more than 2000 km

Table 2. ^{137}Cs contamination density of the soil depth layers within the lower Yenisey study plots [Korobova et.al., 2009]

Location, landscape	Profile index	Floodplain features	^{137}Cs inventory (kBq/m ²)		Elevation above water level (m)
			0–10 cm	0–50 cm	
Upper delta, island floodplain	PSH2-1	High level	1,02	2,20	12,00
	PSH2-8a	Slope	1,33	1,62	9,01
	PSH2-7***	Medium level	2,63	3,14	7,51
	PSH1-3	Low level ridge	3,72	88,10	3,21
	PSH1-1***	Low level depression	3,48	29,32	2,41
Middle delta, coastal floodplain	KR1-12*	Ridge	0,21	0,43	2,90
	KR1-15	Depression	1,50	5,72	3,48
	KR1-25**	Scar (terrace fragment)	0,37	1,60	4,58
Middle delta, island floodplain	TS1-4	Upper medium level, gentle slope	1,38	24,73	4,80
	TS1-8	Flattened medium-level	3,21	19,60	4,60
	TS2-7	Ridge top	0,33	1,53	6,03

Other maximum depths: *(0–75 cm), **(0–25 cm), *** (0–40 cm).

from the source of radionuclide discharge down the stream. Here we discuss the results obtained for three floodplain cross-sections characterizing: 1) the island floodplain in the upper Yenisey delta (the Pashkov Island situated opposite to set. Ust'-Port; 2) the right bank floodplain near set. Karaul and 3) the island floodplain in the central delta part (Island Tsyara). Basing on the data for the sampled soil cores and their relative elevation as presented in Table 2 one should note an indicative variation of ^{137}Cs contamination density of the Yenisey floodplain in the remote zone section.

In general the radionuclide contamination in the lower Yenisey reaches unlike the upper parts was more discrete since the floodplain was subjected to washing out by a larger volume of water and radionuclide sedimentation and fixation was possible in landscape traps, e.g. plot KR1-15, where ^{137}Cs contamination equaled to 5,7 kBq/m².

Following this inference the plot KR1-12 with the contamination density 3–3,5 times lower the global value (Table 2) could have been more typical for the intensively washed floodplain areas in the lower reaches. The

absence of the short-lived radionuclides of ^{60}Co and $^{152,154}\text{Eu}$ in the surface soil layer proved also the "old" age of the contamination event.

The vertical distribution of ^{137}Cs in the soil cores of right-side floodplain near set. Karaul exhibited different patterns. The riverside sandy ridge (KR1-12) had traces of contamination in some layers to a depth of 40 cm. The cores of the peat gley loamy soil taken in a hollow connecting the two thermokast depressions with lakes (KR1-15) and the higher-level soddy loamy sand soil (KR1-25) contained reliably detectable radiocesium quantities with maximum concentration at a depth of 20–25 cm corresponding to silty loam horizons rich in organic matter (Fig. 5).

The island food plain showed itself as a striking example of the relation between the events of radionuclide contamination, hydrological regime of the river and the structure of the river basin and floodplain. Maximum ^{137}Cs contamination reaching 88,1 kBq/m² was observed in the soil core of the plot PSH1-3 located on a low floodplain ridge at the head of the Pashkov Island situated

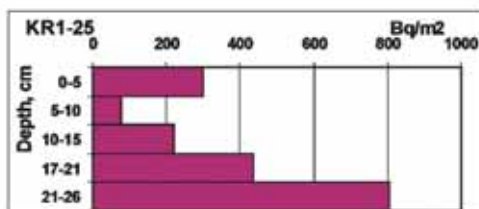
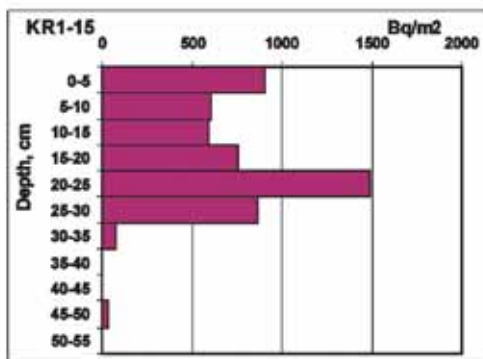
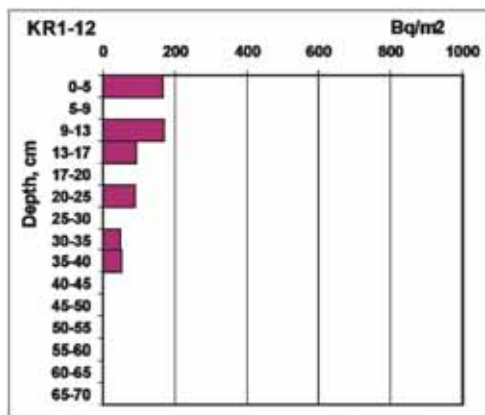


Fig. 5. ^{137}Cs and its contamination density vertical distribution in the floodplain and terrace cores sampled near set. Karaul

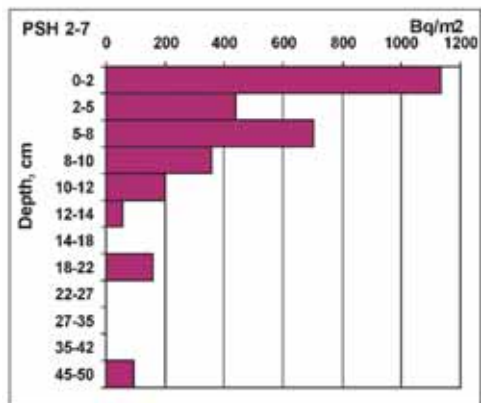
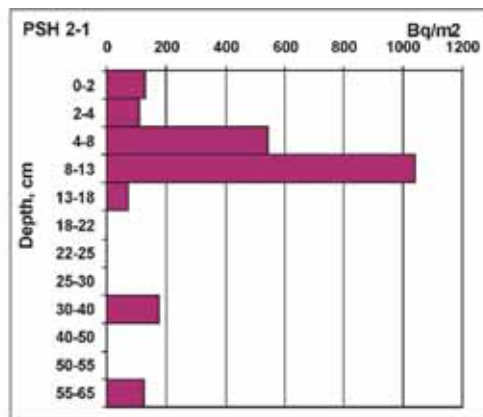
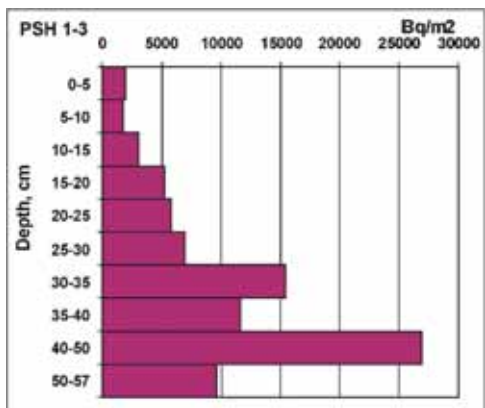


Fig. 6. Vertical distribution of ^{137}Cs the soil cores sampled on the Pashkov Island

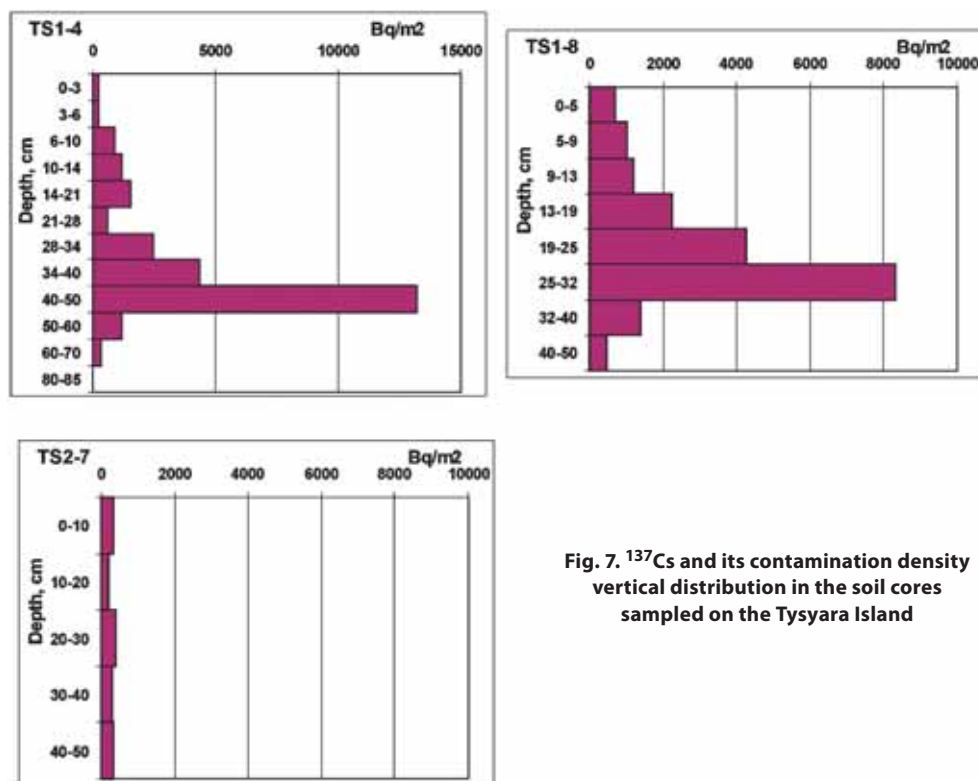


Fig. 7. ^{137}Cs and its contamination density vertical distribution in the soil cores sampled on the Tsyara Island

at the beginning of the Yenisey upper delta (Fig. 6). The density of ^{137}Cs contamination of the middle level (PSH2-7) and high level (PSH2-1) floodplain considerably decreased to 3,14 kBq/m² and 2,2 kBq/m² correspondingly that is only slightly higher than the global background value.

The location of maximum contamination at the depth of 40–50 cm proved its old age and its river origin. On the other hand, in case of the total low density of contamination and the maximum ^{137}Cs content in the surface soil layer observed on the middle and high floodplain showed domination of the aerial source of ^{137}Cs over the regional technogenic due to operation of the KMCC.

The plot studied on the other island floodplain (the Tsyara Island) also presented strong evidence of the old contamination of this island and a much lower contamination of this location in the subsequent periods of flooding. The two soil cores TS2-4 and TS2-

8 located at different elevation levels had evident buried peaks of ^{137}Cs activity at the depth of 40–50 cm and 25–32 cm indicating considerable contamination event which could be related to radionuclide discharge during high water of 1966 (Fig. 7).

No clear traces of the 1988 discharge were observed. The upper soil layers down to 6 cm referred to river deposition after 1992 when the reactors were shut down. The activity of ^{137}Cs in these layers was close to that of the soils core located on the high level floodplain TS2-7. The low contamination of the latter core taken on the ridge top (1,53 kBq/m²) and an even vertical distribution of ^{137}Cs corresponded to the pattern of river distribution of the global ^{137}Cs fallout rather than of the KMCC radionuclide discharge.

CONCLUSIONS

Modern structure of radionuclide contamination of the Yenisey floodplain

landscapes depends upon a complex of different factors. A durable and unstable release of radionuclides to the flooding areas due to irregular KMCC discharges matched with different hydrological regimes of the Yenisey river and a complicated morphological structure of the floodplain landscapes has produced an exclusively complicated pattern of radioactive contamination of the Yenisey floodplain in both the spatial and temporal manifestation.

The near KMCC impact zone is characterized by a continuous contamination the middle and low-level floodplain while contamination of the remote zone was local. In general maximum of radionuclide load has been deposited in the low floodplain locations with domination of silty, peat and light loam deposits. In the near and middle impact zones of KMCC the radionuclide traces have indicated two events of maximum contamination related to discharges during high water in the years of 1966 and 1988 while in the remote zone a single event of enhanced contamination

was found that presumably corresponded to radionuclide dumping in 1966.

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RISK ASSESSMENT BASED ON MATHEMATICAL MORPHOLOGY OF LANDSCAPE MODELS (CASE STUDY OF THERMOKARST PLAINS)

ABSTRACT. The paper presents a new approach for risk assessment of impact of thermokarst processes on engineering structures; it is based on the methods of mathematical morphology of landscape. The paper presents the results of the investigation of irregular (non-circular shape) thermokarst lakes. Remote sensing images of reference plots with thermokarst lakes were digitized; then, theoretical assumptions were applied and the simulation results were compared with empirical data to prove convergence. The analysis of the obtained results showed general agreement of empirical and theoretical data

KEY WORDS: risk assessment, remote sensing, landscape pattern analysis, mathematical morphology of landscape

INTRODUCTION

One of the urgent modern tasks in assessment of the risk associated with development of exogenous geological processes. The most common risk assessment parameters are:

- The probability of some degree of damage to engineering structures from exogenous process.
- The average risk – the mathematical expectation of losses (e.g., area or length) of an engineering structure by a hazardous exogenous process.

- The probability distribution of damage of an engineering structure by a hazardous exogenous process.

Risk assessment is the subject of many studies [e.g., Assessment and Natural Risk Management, 2003; Yelkin, 2004; Ivanov, Dulov, Kuznetsov, et. al., 2012], however, the task is still urgent. The difficulty is associated with the fact that processes, which allow assessing the probability and the size of damage are poorly studied. In the statistical approach, it is difficult to obtain a large volume of statistical data on damage to structures, especially considering every type of physical and geographical conditions that an engineering structure encounters. The time required to obtain such data is comparable with the time of operation of an engineering structure, however risk assessment is needed at the design stage of construction. Therefore, this approach is not very promising.

Previously, the possibility and the ways of use of morphological structure models in engineering structures risk assessment has been demonstrated for a number of genetic types of areas [Victor, 2006; Victorov, 2007, Victor, Kapralova, 2011]. However, the problem was solved for the simplest case, when the foci of the processes have a circular shape, and, thus, the solution was applicable for a limited number of situations.

OBJECT AND METHODS OF THE STUDY

The goal of the study presented herein is to demonstrate the solution to a problem of risk assessment using morphological structure models for a number of genetic types of the territories with the irregular shape foci of hazardous processes. The research was conducted using thermokarst lake plains as an example (Fig. 1).

The investigated type of terrain represents a sub-horizontal undulating surface with predominance of tundra vegetation, and with interspersed thermokarst lakes randomly scattered across the plain. Initially, emerging foci of thermokarst processes (lakes) are characterized by an almost round shape, but in the process of development, they tend to merge and, thus, the shape of the foci may differ significantly from a circular (Fig. 2). It is specifically this last factor that creates significant challenges in risk assessment.

In the process of development, the foci of thermokarst processes may undergo the following stages:

1. In the emergence of the primary focus, the major factor seems to be the accumulation of a relatively large water layer in depressions [Perlstein, Levashov, Sergeev, 2005];

2. The expansion of the focus (thermokarst lake) due to the thermoabrasive impact; its speed depends on many random factors (average air temperature, permafrost ice content, soil composition in the vicinity of the lake, etc.);

3. Possible merging with other adjacent lakes.

The solution to the task of risk assessment may be based on the morphological structure model for a thermokarst lake plain [Viktorov, 1995; Victorov, 2005, Victor, 2006]. Let us consider a thermokarst lake site, homogeneous in respect to its physical-geographical and, first of all, geomorphological properties. The model was based on the following assumptions:

1. The process of emergence of the primary depressions is probabilistic and occurs in non-overlapping areas (Δs) and



Fig. 1. A typical landscape of a thermokarst lake plain

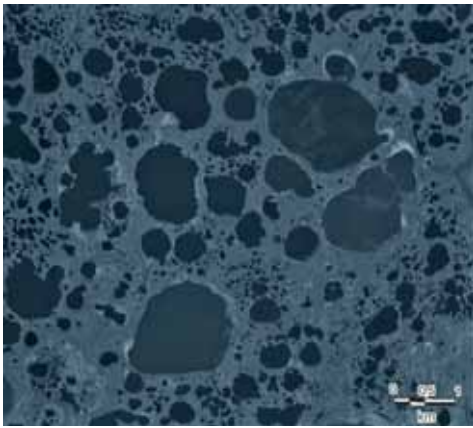


Fig. 2. A typical landscape of a thermokarst lake plain in remote sensing

at non-overlapping time periods (Δt); it is independent; the probability of emergence of a single depression is significantly greater than the probability of emergence of several depressions, that is,

$$p_1(t) = \lambda(t)\Delta s\Delta t + o(\Delta s\Delta t) \quad (1)$$

$$p_k(t) = o(\Delta s\Delta t) \quad k = 2, 3, \dots, \quad (2)$$

where $\Delta(t)$ means the density of newly appearing depressions per unit area at time t .

2. The growth in the size of the lakes due to thermoabrasion is a random process and is independent of the other lakes; in the course of development, the lakes can merge.

The assumptions seem to be reasonable since they are derived assuming the homogeneity of the study area and using existing ideas about the mechanism of the process.

This foundation provides the basis for a rigorous mathematical analysis of the assumptions in order to obtain consistent patterns of the structural features of a thermokarst plain [Viktorov, 1995; Victorov, 2005, Victor, 2006]. Thus, the distribution of thermokarst depressions (foci) at a randomly selected site meets the Poisson distribution, that is,

$$P(k, t) = \frac{[\mu(t)s]^k}{k!} e^{-\mu(t)s}, \quad (3)$$

where s is the area of the test site, $\mu(t)$ is the average number of depressions per unit area per unit time t . The density of depressions in general depends on time since the emergence of new thermokarst lakes is possible and, even in the absence of new lakes, existing lakes can merge.

The Poisson distribution of lakes is confirmed by our experimental data (Fig. 3) and other publications [Victorov 1995, 2006; Polishchuk, 2012; and others].

SIMULATION RESULTS

Let us compute the probability of damage of a linear structure of a given length (L).

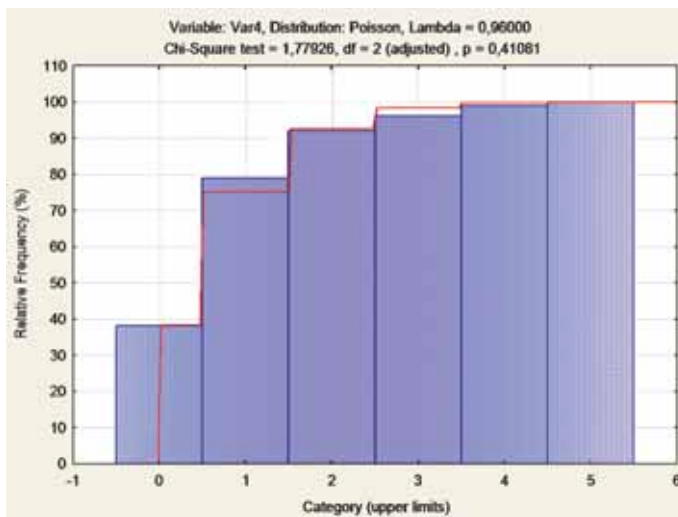


Fig. 3. Comparison of the theoretical and empirical distribution of the number of thermokarst lakes at a random site

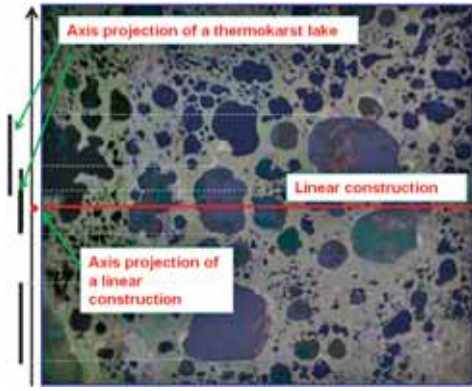


Fig. 4. Schematic representation of the procedure for probability assessment of damage to a linear structure (explanation in text)

First, we will consider the band of a finite width R (Fig. 4), at whose axis the linear structure is located. Consider a coordinate axis x perpendicular to the linear structure.

In the projection, this axis is represented by a point, the focus of thermokarst – by a segment, whose length corresponds to its projection on the axis. The damage of the linear structure is expressed as the intersection of the segment and the point. It may be easily demonstrated that the Poisson distribution of the foci at a site determines the Poisson distribution of their projections on the axis and, therefore, the equal probability of locations of the foci projections at given segments of the axis and their independence from each other. The probability (α) of the event when one, out of a given number, focus touches the linear structure (i.e., that the point corresponding to the projection of the linear structure will be inside the projection of the focus) depends on the above mentioned relations between the length of the focus projection and the width of a given band. This, considering the probability of different projection sizes, gives the following expression:

$$\alpha = \int_0^{2R} \frac{x}{2R} f_p(x, t) dx \quad (4)$$

where $f_p(x, t)$ means the distribution of the sizes of the foci projections at time t . The probability of the event when none of the foci touches the linear structure and

assuming that their number equals k and the centres are independent, is:

$$P^0(k, R, t) = (1 - \alpha)^k \frac{[2\mu(t)RL]^k}{k!} e^{-2\mu(t)RL}. \quad (5)$$

The level of safety (probability of damage) of a linear structure at a random number of the foci in the band may be obtained by summation over k and transition to the limit at unlimited extension of the given band ($R \rightarrow +\infty$)

$$\begin{aligned} P_{nl}^0(R, t) &= \\ \sum_{k=0}^{+\infty} (1 - \alpha)^k \frac{[2\mu(t)RL]^k}{k!} e^{-2\mu(t)RL} &= \\ = e^{-2\mu(t)\alpha RL} \end{aligned} \quad (6)$$

since

$$\lim_{R \rightarrow +\infty} 2\alpha R = \int_0^{+\infty} x f_p(x, t) dx = \overline{pr}(t), \quad (7)$$

where $\overline{pr}(t)$ means the mathematical expectation of the value of the foci projections at time t , therefore, after reduction the safety is

$$P_{nl}(L, t) = e^{-\mu(t)\overline{pr}(t)L} \quad (8)$$

Hence it is clear that the probability of damage of a linear object with the length L by at least one focus is

$$P_{dl}(L, t) = 1 - e^{-\mu(t)\overline{pr}(t)L}. \quad (9)$$

If a linear object has a shape of a curved line, this result may be considered a baseline. To assess the risk in this case, the curve should be approximated by a kinked line, and the probability of damage is computed for its segments according to (9).

Let us compute the probability of damage of an areal structure of a spherical shape with a given radius (l). The damage of the structure by the focus of the process at time t occurs in one of the two events:

- The center of the structure is within the focus contour,
- The center of the structure is outside the contour, but at a distance from the focus less than l .

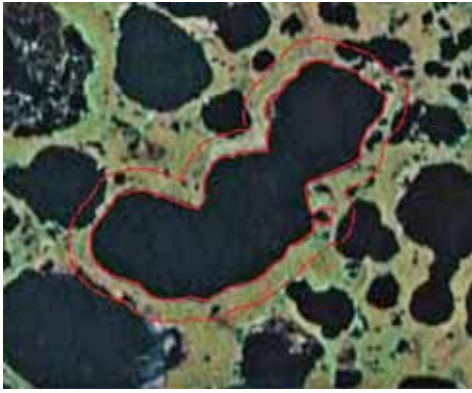


Fig. 5. Example of the l -buffer of a thermokarst focal point

The latter means that the center of the structure is in the l -buffer of the focus of the process. Let's denote the l -buffer of a shape by a set of points of the area outside its focus, but at a distance less than l (Fig. 5).

Thus, the probability of damage of the areal structure is equal to the product of the probabilities of the two above-mentioned events.

It is natural to conclude that the probability of the center of the structure to be within the contours of any focus considering the assumption for the focus area of its independence on the location and mutual non-intersection of the foci at a given moment, is

$$P_1(t) = \mu(t)s(t), \quad (10)$$

where $\mu(t)$ means the average number of the foci per unit area at time t ; $s(t)$ means the average area of one focus at time t .

To determine the probability of the second event, let us first review the circular area, where the structure is located, bounded by radius R . The probability of the event when the center of the structure will be within the l -buffer of the focus (i.e., the focus will "touch" the structure) is defined by the ratio of the area of the l -buffer of the focus and the entire area of the circular shape and considering the probability of formation of the buffers of the foci with different area is

$$\alpha(l, t) = \int_0^{\pi R^2} \frac{x}{\pi R^2} f_b(x, l, t) dx, \quad (11)$$

where $f_b(x, l, t)$ means the density of the distribution of l -buffer area of the focus at time t . Then, applying the algorithm for a linear structure presented above, evaluating the probability of the event that none of the foci touches the areal structure, assuming their number within the band is k , and eventually transitioning to a random number of the foci and extending the circular shape fairly, we get

$$P_2(l, t) = e^{-\mu(t)s_b(l, t)}, \quad (12)$$

where $s_b(l, t)$ means the average size of the l -buffer at time t given by the expression

$$s_b(l, t) = \int_0^{+\infty} x f_b(x, l, t) dx. \quad (13)$$

Thus, the overall probability of the circular structure with radius l in this model is

$$P(l, t) = 1 - [1 - \mu(t)s(t)]e^{-\mu(t)s_b(l, t)}. \quad (14)$$

The formula can be greatly simplified if the foci have a convex or a convex-concave

shape, but with curvature of at least $-\frac{1}{l}$, in

other words, if a concave site has smaller curvature than the boundary of the structure. In this case, we can analytically derive the following expression

$$s_b(l, t) = l\bar{p} + (t)\pi l^2, \quad (15)$$

where $\bar{p}(t)$ means the average perimeter of the focus at time t .

Accordingly, the probability of damage of the circular areal structure with radius l in this case is

$$P(l, t) = 1 - [1 - \mu(t)s(t)]e^{-\mu(t)[l\bar{p}(t) + \pi l^2]}. \quad (16)$$

The buffer-concept generalization allows us to find the expression for the areal-structure of not a circular, but of a complex form. In this

case, the buffer means the area surrounding the focus boundary, so that when it contains the center of the structure of given shape (C) and bearings, the focus touches the center of the structure. In these conditions, the buffer is a function of four factors: (1) the contour of the focus, (2) the contour of the structure, (3) the angle between the line connecting the focus and the center of the structure, and the diameter of the focus, and (4) the angle between the line connecting the focus and the center of the structure, and the diameter of the structure.

Overall, the analysis shows that the expression for the probability of damage of the areal structure is

$$P(l, t) = 1 - [1 - \mu(t)s(t)]e^{-\mu(t)s_b(C, t)}, \quad (17)$$

where $s_b(C, t)$ means the average size of the focus buffer at time t in relation to the engineering structure of a given shape (C).

Thus, the probability of damage of an areal structure at a given time depends on the average density of the foci, average area of a focus, and average area of the buffer of a structure of a given-shape. This set of parameters differs from the set of parameters in the computation of the probability of damage for a linear structure.

Solving the latter problem, we have actually solved the problem of the probability of merging of thermokarst lakes over time-period $[0, t]$. For this, it is sufficient to substitute the second focus for the engineering structure and to assume that its contours have some probabilistic distribution similar to the first focus. It is clear that the angle of the relative orientation of the foci (the angle between the diameters), due to the homogeneity of the conditions of the site, will have a uniform distribution on the segment $[0, 2\pi]$. As a result, the probability of the foci merging in the interval $[0, t]$ is

$$P_f(t) = 1 - [1 - \mu(t)s(t)]e^{-\mu(t)s_b(l, t)}, \quad (18)$$

where $f_{bi}(x, \alpha, t)$ means the density distribution of the area of a thermokarst

focus in relation to another focus, at α angle of the relative orientation at time t ; $s_{bi}(t)$; means the average area of the thermokarst focus buffer in relation to another focus at time t , given by the expression

$$s_{bi}(t) = \int_0^{2\pi} \int_0^{+\infty} \frac{1}{2\pi} x f_{bi}(x, \alpha, t) dx d\alpha. \quad (19)$$

From this formula, it is easy to obtain by differentiating the probability of the lake merging with some other lake at a given time-period $[t, t + \Delta t]$.

$$P_c(t, t + \Delta t) = \left[\frac{1}{1 - \mu(t)s(t)} \frac{d}{dt} \mu(t)s(t) + \frac{d}{dt} \mu(t)s_{bi}(t) \right] \times \Delta t + o(\Delta t). \quad (20)$$

DISCUSSION

The obtained expressions for linear structures were initially field-tested at standard plots (West Siberia). The testing of the expression for the assessment of the probability of damage for a linear structure was based on the following reasoning. Let us assume that we are at a given site before the start of the thermokarst process. Because the site is homogeneous, we do not have any reasons to prefer some specific location for a linear structure over another and the structure can be located, with equal probability, at any point at the site. The foci emerging in the future, visible now on the image, could have damaged or not the linear structure.

Considering this reasoning, the development of events in real conditions was simulated in the following way: using programming tools and the random number generator, we randomly placed a linear structure (segment) within a selected site (with already existing process foci) and,

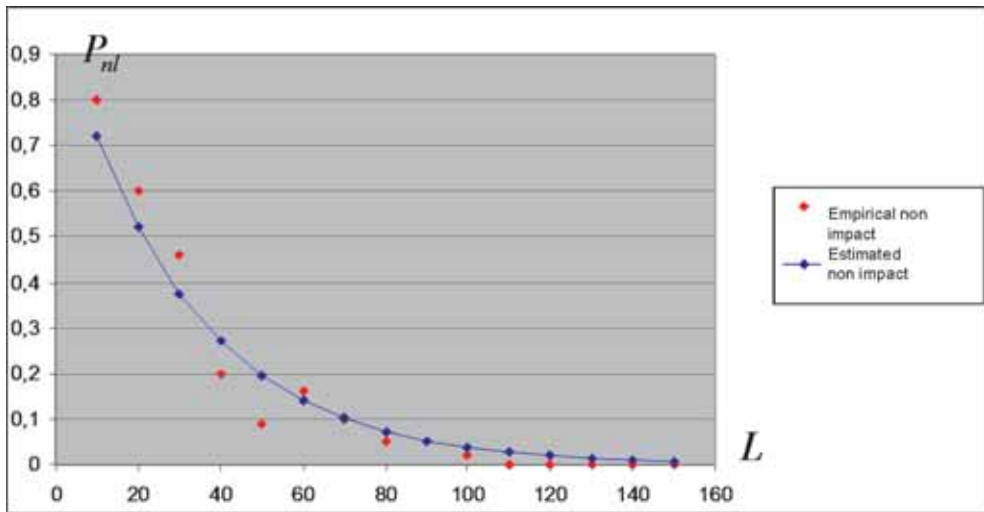


Fig. 6. Comparison of the theoretical and empirical probability of damage for linear structures

then, estimated the number of lines, not intersecting the foci. The obtained number of the linear objects not damaged by a focus (in fractions of the total number of cases) was compared with the computed numbers from expression (8).

The procedure was repeated for linear structures (segments) of different length. The test produced positive results (Fig. 6).

The model presented herein is the basis for the use of remote sensing in risk assessment, for example, in selecting a shape of alignment of a linear facility. Considering the information presented above, the procedure for a linear structure (for example) should contain the following basic elements:

- Forecast based on repeated computations of mathematical expectation of projections that appear over the duration of the structure functioning, on the axis perpendicular to the bearing of the linear structure (linear interpolation or linear interpolation of the mathematical expectation of the projection logarithm);
- Computation of the probability of damage using the obtained expressions (9).

In addition, it is necessary to account for already existing foci using the logonormal distribution [Victorov, 2007]; the parameters are defined from repeated surveys.

At the present time, design of a linear structure, for example, practically does not provide for quantitative assessment of the probability of damage of the structure over its lifetime by existing or appearing foci of exogenous processes. Karst risk represents an exception [Recommendations for Engineering Surveys..., 2012], however, strictly speaking, the recommendations refer to the risk of damage for 1 ha of area, and not to a linear structure; moreover, the recommendations do not account well for the size of the karst foci.

In our analysis, we have not used significantly the mechanisms of the thermokarst process, but only the fact that the distribution of the foci has the Poisson character and they change independently of each from one another. Therefore, the results obtained can be extended to other processes, where foci emerge and develop independently (for example, swamping, subsidence, etc.).

CONCLUSIONS

1. The expressions for risk assessment of linear and areal structures damage by processes with the Poisson distribution and with free-shape foci (thermokarst, collapsibility, karst, flooding, etc.) have been obtained.
2. The model of the morphological structure of thermokarst lake plains development

has been obtained; the model considers thermokarst lakes merging.

3. It has been demonstrated that zoning for risk associated with damage of linear and areal structures does not coincide in general case because the probabilities of damage risk depend on different parameters for foci of different hazardous processes. ■

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LOCAL INITIATIVES FOR SUSTAINABLE DEVELOPMENT IN RURAL HOKKAIDO: A CASE STUDY OF SAMANI

ABSTRACT. The paper presents the results of a field investigation about sustainable development of Samani town – a rural area in Hidaka region, Hokkaido, Japan. Local activities, business, environmental, social and economic challenges that affect the town as well as the advantages were investigated. The research was done by means of field visits, questionnaires and interviews involving the local people and government. The main economic sectors: olivine industry, fishery, agriculture and tourism were targeted as well as the government sector and the local high school with a particular focus on rural-urban migration. Samani has quite unique natural features on hand but a few strong comprehensive challenges on the other hand. The authors focused on the citizens opinions and positions which were based on the uniqueness of Samani and their own local activities and initiatives for the sustainable development of the town in the future which can be replicated in other rural communities around the world.

KEY WORDS: social research, rural development, rural depopulation, geopark, sea temperature rising, eco-product

INTRODUCTION

Rural areas in Japan are plagued with a common problem of declining population which began during the industrialization

and modernization of the country due to rural-urban migration [Matanle, 2008]. This has been further exacerbated in recent years due to a decrease in births and an aging in the population which has resulted in some village communities virtually ending its existence. Schools have closed nationally in Japan at a rate of 400–500 per year due to this problem [Nobuo, 2012]. In some extreme cases even the post office closes its doors. But all is not lost, there have been initiatives both from the Government as well as people driven that have sought to curb this issue. One example that arose out of this problem was the emergence of the One Village One Product (OVOP) movement which has been promoted throughout Japan and in other parts of the world. This community centered and demand driven regional economic development approach was initiated by Oita prefecture in Japan in the 1970's with one of the objectives being to prevent depopulation [Oita OVOP International Exchange Promotion Committee, 2012]. A regional workshop was held during the 9th Science and Technology Foresight and was aimed at drawing up a regional model fully compatible with the environmental conditions of the region, wherein citizens live comfortably [National Institute of Science and Technology Policy, 2010]. This research was initiated by the Science and Technology Foresight Center of Japan to discuss with



Fig. 1. Location of Samani town [Aoki, 2006]

representative stakeholders a wide range of issues from the viewpoint of realizing the desired future society.

Samani town is located in the northern island of Japan called Hokkaido. The town's name is said to come from the Ainu term *sanmauni*, which means "place of withering trees" [Mt. Apoi Geopark Promotion Council, 2013]. It is part of the Hidaka region and is found between Urakawa and Erimo (Fig. 1). There is apparently another meaning "place of the otter" which suggests that otters may have populated the area in the past and then became extinct. Samani has had its equal share of the effects of this problem and is facing the same challenges that are common to other rural areas in Japan. Since citizens believe that the uniqueness of Samani could help in its sustainable development, how do we leverage existing practices in Samani to strengthen the relationship between humans and nature with the goal of it becoming a *model sustainable town*? How do Samani people see their future and what features, advantages and disadvantages do citizens regard as most important? This research is premised on the belief that the optimal way of sustainable development of the rural regions lays in a comprehensive approach: citizens' knowledge and governments' support. The objective of this research is find out the strengths of Samani from the citizens' point of view, thus providing a way forward for its citizens. It is hoped that the lessons learnt can be reproduced in

other rural areas as well conducive to the realization of the ideal social model of each region in the future.

MATERIALS AND METHODS

This research was completed during the Follow-up Program of international summer school "Sustainability for coupled human and nature" under the auspices of the Global Center of Excellence, Hokkaido University and the Samani government in November 2012. The investigation was carried out in Samani town which pertains to the Hidaka Subprefectural Bureau of Hokkaido. It has an area of 364,33 km² and a current population of 5,029 as of March 31st, 2012 [Japan Autonomous Academy, 2012].

The research was done by means of field visits, questionnaires and interviews with the local people and government. We studied the main economic sectors, namely, olivine industry, fishery, agriculture and tourism; investigated the government sector (divisions included education, commerce, administration, tourism, tax, forestry, water, library, civil and disaster preparedness); enterprise (seafood, sports gear, convenient store and the private sector commission); and the local high school with a particular focus on rural-urban migration. One field visit was done per sector and was facilitated logistically by the Government of Samani.

A total of 25 interviews were conducted reciprocally in Japanese and English,

facilitated by an interpreter. The interviews were audio recorded for further analysis and notes were taken simultaneously in triplicate and merged into one document at the end of the interview. Persons were selected from each of the sectors based on their willingness to participate and availability. Each interview had 9 core questions which were accompanied by several follow-up questions. The main questions were with regard to advantages and disadvantages of Samani and challenges for their business (economical, social and environmental aspects).

A total of 168 questionnaires were collected and analyzed. Questionnaires were distributed at the Samani Government Office, the high school, and the Samani Food Festival which coincided with our research period. Depending on each participant, a range of 6–12 questions would have been answered per questionnaire. All questionnaires were done in Japanese.

A meeting on Disaster preparedness between Samani and Noda towns which occurred during our research period was attended and formed a part of our investigation. A town hall meeting was held successfully to present our preliminary findings to the citizens and obtain feedback from them. Finally, a presentation with recommendations was made to the Samani Government for their consideration and possible implementations in the future.

RESULTS AND DISCUSSION

The Local Food Festival, an annual event in Samani, was a good opportunity for us to interact with citizens and learn more about the unique features of Samani, its activities and traditions. At the festival, 95 questionnaires were collected with 82% of the participants from Samani and the rest being visitors from Urakawa, Erimo and Sapporo. The results showed that citizens consider the festival as a local food fair while visitors saw it as an avenue for advertising Samani products. Besides the food sale, there were social activities that were family oriented as well, which is a rather important

feature for rural communities. According to the responses, participants believed that this annual activity serves to promote local culture and cuisine (48%), social awareness and cultural heritage (43%) and community development (48%). Since Samani is still not as well known as its neighbouring communities (Erimo and Urakawa), the festival can serve to improve its image if it is adequately advertised, thus attracting more visitors. This would be beneficial to the citizens since they can sell their products to persons of other regions of Hokkaido and it can be coupled with sightseeing for other visitors who are interested, thus showcasing Samani.

Fishery is one of the main sectors in Samani (kelp, whelk and salmon), a similar feature to other coastal towns in Hidaka region and Hokkaido as well. Samani has had this fishing culture from the time of the Edo period and its fishing ground is located where the Kuroshio Current (warm waters from the south) meets the Oyashio Current (cool waters from the north) which is very fertile. What is important is that the four fishermen interviewed all highlighted issues related to the environment as critical to the industry. Climate change and sea temperature rise affected the sector resulting in a decline in catch, kelp spoilage (Fig. 2) and infiltration of warm water species. Salmon catch has



Fig. 2. Good quality kelp (left) and spoil kelp (center and right) (Photo by D. Dublin)

particularly declined over time [Miyakoshi *et al.* 2008]. The fisher folk seems quite informed in this regard and share a working relationship with researchers. There are already various types of activities to deal with this issue such as earlier harvesting of kelp and the planting of rocks to facilitate new kelp growth.

In the agricultural sector, four farmers were interviewed. They mentioned mild climate as a good climate resources and highlighted the economy as their main concern. The fact that they need expand their farms but land change is difficult also limits their development. Because of these issues, social problems arise since the next generations of farmers are looking for more lucrative business opportunities. To achieve this, new product (strawberry) or special labeling is being used to increase the price of products. The most notable is the “Yes! Clean” label used for rice which replaces commercial fertilizers by 50% with animal manure, a good way of having crop and animal farming integrated. In addition, this label can only be applied to products grown in Hokkaido, so this helps the cause of Samani due to its location on the island as well [Department of Agriculture Hokkaido Government, 2011]. Most of the farmers are aged and their children show little or no interest in continuing the farms. As a result, most of them are considering hiring persons to run the farm, lease it or sell it to others only if they are interested in farming. This is indicative of the cultural attachment to farming. As a horse farming area, this is a welcome initiative since many young people are still interested in the horse business and have developed a regional online community for young horse farmers where they exchange pertinent experience in their business. For business development farmers look to agrotourism and horse-therapy service in the future.

The Toho Olivine Company was the only site visited in the industry sector but this is by no means a limitation since it is the most important industry in the town. This is because peridotite rocks are quite unique

to Samani town and this company does a lot to commercialize it for various uses due to its many properties. It forms an important part of the citizen's lives since the rocks can be seen in many sculptures, in construction and in use for drying kelp. Beside this peridotite rocks provide rivers and coastal waters for fertilize. This rock is also the reason why the town has found itself in the Japan GeoparkNetwork and is seeking recognition as a Global Geopark. Due to the obvious destruction of the natural environment, the company spends time on the replanting of trees after mining would have been completed in the area (Fig. 3). Against this background, a balance is struck between mining and environmental health.

The tourism sector continues to attract quite a number of tourists although lower than the maximum capacity of available accommodation. Many tourists are specialists, researchers or eco-tourists with particular interest in geology, biology and such like. The four interviews conducted revealed that there are ideas of promoting the town as an alternative to the harsh winter in Hokkaido, a fact that is not well-known. Already a food festival was launched with fair success and discounted rates and campaigns are advertised. The hotel owners said that there is a need to increase awareness, cultural knowledge and history among residents and the need for the existence of signs and information for tourists so that they can find themselves around quite easily. Some local people have made attempts to promote Samani via internet blogs and forums with a big enthusiasm.

The private sector is still somewhat vibrant in spite of the decline in population. This social aspect continues to hurt the business community who also happen to be aged. From the four interviews conducted, there was an expression of the view for better infrastructure and connectivity in the Hidaka region, since collaborative efforts would benefit the business community in a large way. The Private Sector Chamber of Commerce is filled by businesses of various



Fig. 3. Replanting of trees in a mined out area by Toho Olivine Company (Photo by A. Bancheva)

types and there is the common goal of having continuity and prosperity in the region.

At the Samani Governance Office, 7 interviews and 26 questionnaires were collected from persons attached to various departments. It must be noted that while the government officers offered ideas and opinions that were very similar to the official position, it also corresponded with what was found on the ground with the general citizenry. There seems to be little disconnect with the reality on the ground which shows that the office has a fairly good working relationship with the citizens and are in sync with their needs. A disaster preparedness meeting which was held between the sister towns of Noda and Samani, demonstrated a close

neighbourly relationship between the two. Many mechanisms are in place to deal with possible natural disasters, mitigation of their effects, risk assessment, response in times of disaster and recovery after disaster would have struck.

The high school was visited specifically to explore rural-urban migration, since this trend further exacerbates the depopulation, low fertility and aged society phenomenon which is a common feature in Hokkaido and Japan at large (Fig. 4). Currently Samani only has an average of 20 births annually and 70 deaths per year [Samani Government, 2011]. The students and teachers were consulted with 47 questionnaires received and an interactive session was conducted.

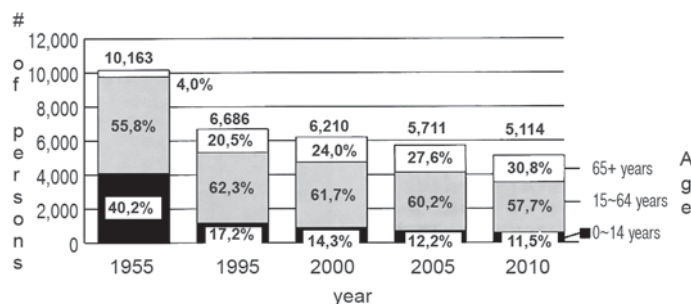


Fig. 4. Population change in Hokkaido [Bureau of Regional Planning and Promotion, 2008]



Fig. 5. Participants at the town hall meeting in the brain storming exercise (Photo by D. Dublin)

The children expressed the view that jobs were their main reason for wanting to leave but this is in direct contradiction to the businesses that said there are vacancies but Samani residents are not filling them and as such persons from Urakawa and Erimo have to fill these slots which indicates that apart from jobs. According to the answers 38% of students want to stay in Samani. They would like to have jobs in the local town office, bank, post office and factories; as well as in childcare and hospitality. Other students want to further their studies and only few of them want to return to Samani after graduating from university. Currently many middle-aged persons return to take care of their aged parents and oversee their businesses. Teachers are all from foreign areas and as such do not have enough attachments to the local community to want to deal with this issue.

The town hall meeting was held and it cemented our findings since the feedback obtained from the citizens demonstrated that their opinions were correctly reflected in our findings. The idea of “town hall meeting” is gathering citizens in one time in one place to discuss the theme “Future for Samani”. The advantage of this meeting is a possibility to gather people of all ages and all professions. People from government take a part as well. Participants were randomly grouped and asked to name

several topics the most important for the future of Samani (Fig. 5). There were ‘nature’, ‘independent/self-sufficient Samani’, and ‘industrial development’. The next task was to come up with specific actions to make those dreams of the future come true. The groups reconvened, brainstormed a list of ideas, and settled on which ones seemed the most exciting: marketing nature, solar electricity, and exporting new value-added goods. These ideas are important since nature conservation for a calm countryside and industrial development can both be achieved cohesively. Therefore, the town hall meetings with citizen involvement could be an important strategic planning instrument.

CONCLUSIONS

Being famous mostly because of its geology, it was the first time in Samani that a research of this nature, that is with a very large social component was embarked upon in the town with results that are workable and applicable by the citizens and the administration. Our results reflect almost completely the feelings and sentiments of the citizens about town development and indicates therefore that the people of Samani are capable of determining what they want for the future, where they want to go and how to get there realizing their own pros and cons without the influence of outsiders. This has been proven in various ways around the world such as in

the forest communities of East Kalimantan [Sari, 2009], agricultural communities in Northeast Thailand [Hirokawa, 2010] and disaster management in Bangladesh and Vietnam [Shaw, 2006].

Moreover, there are initiatives citizens are involved in, that contributes towards the general wellbeing and development of the town. These include locally branded products promoted at local festivals designed to enhance and promote community building; the partnering with the scientific community for sustainable fisheries; the compatible mining of economically important ores in an environmentally friendly way; and regionally branded agrotourism collectively

contribute to sustainable development with a multisectoral approach. It can be concluded that similar exercises should be conducted in other rural towns globally, thus reciprocating people driven sustainable development in other parts of the world.

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URBAN VULNERABILITY AND ADAPTATION TO EXTREME WEATHER EVENTS: A CASE STUDY OF RAINSTORM VICTIMS IN ILORIN, NIGERIA

ABSTRACT. Nigeria is a disaster prone country. The disasters which often result into environmental emergencies like flooding are worsened by the degradation of the country's environment and natural resources. Floods, rainstorms and droughts affect households each year in Ilorin and contribute to endemic poverty in most parts of Kwara State. Anticipated increases in extreme weather events will exacerbate this. Using data from both primary and secondary sources the study examines the urban vulnerability and adaptation to climate change among flood and rainstorm victims in Ilorin, Nigeria. The primary data include questionnaire administration to victims in the affected areas of the city. The secondary data on the other hand, include data from the Kwara State Emergency Management Agency on flood victims in the State between 2002 and 2007. This study brings out the important issue of vulnerability, coping and adaptation to weather induced disasters among the urban poor. The study revealed that the indigenous coping mechanisms employed by the poor may become less effective as increasingly fragile livelihood systems struggle to withstand disaster shocks. Also, many of these long-term trends are rendering indigenous coping strategies less effective and thus are increasing the vulnerability of the poor.

KEY WORDS: climate change, disasters, flooding, vulnerability, adaptation, Nigeria

INTRODUCTION

The twin-issues of climate change and global warming have attained global dimensions evident by their recurrent discussions at the UN General Assembly, the Bali, Kyoto Conferences and other International Meetings. Global climate change, driven largely by anthropogenic activities, is a growing threat to human well-being in developing and industrialized nations alike. Significant harm from climate change is already occurring, and further damages are likely [Gwary, 2008].

The vulnerability situation, the present and predicted impact of climate change on urban areas is particularly worrisome. According to Satterthwaite et al [2007], the scale of the devastation to urban populations and economies caused by extreme weather events in recent years highlights their vulnerabilities. Worldwide, there has been a rapid growth in the number of people killed or seriously impacted by storms and floods and also in the amount of economic damage caused; a large and growing proportion of these impacts are in urban areas in low- and middle-income nations (Fig. 1a and b).

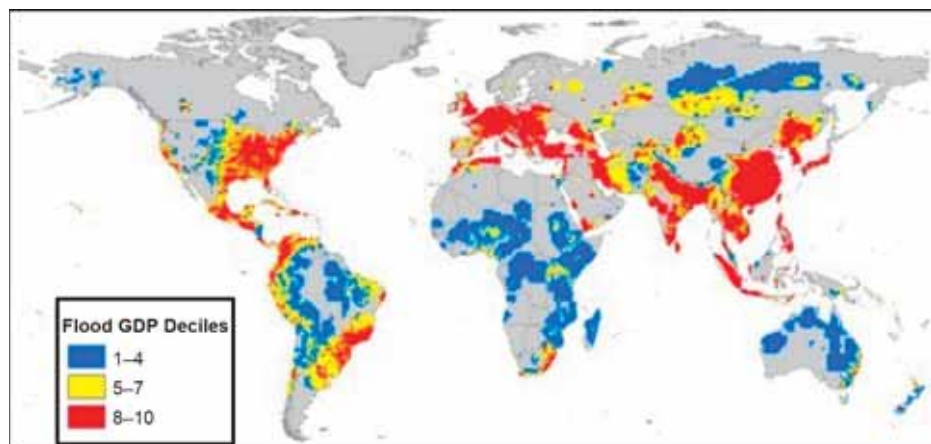


Fig. 1a. Economic losses from flood disaster

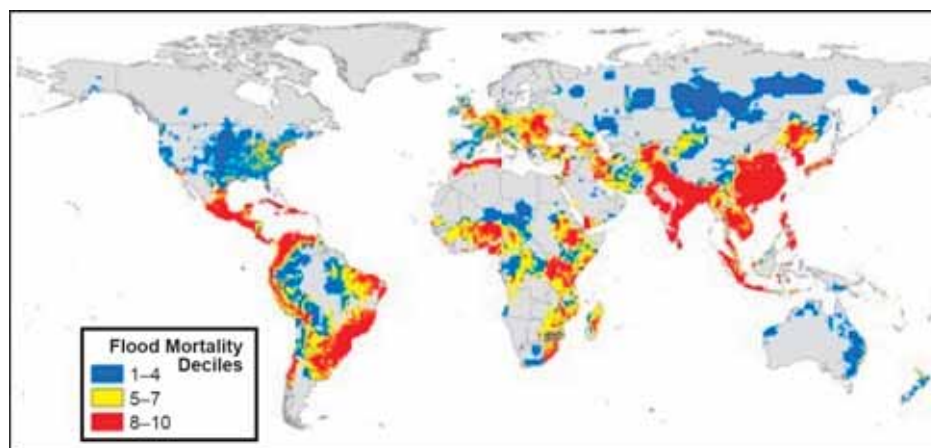


Fig. 1b. Flood disaster mortality

[World Bank Hot Spots: Dilley, Chen, Lerner-Lam et al, 2005]

Climate change is likely to have been a factor in much of this, but even if it was not, it is proof of the vulnerability of urban populations to floods and storms whose frequency and intensity climate change is likely to increase in most places.

Henderson [2004] revealed that this level of risk and vulnerability in urban areas of developing countries is attributable to socio-economic stress, aging and inadequate physical infrastructure. Indeed, according to Satterthwaite et al [2007], hundreds of millions of urban dwellers have no all-weather roads, no piped water supplies, no drains and no electricity supplies; they live in poor-quality homes on illegally

occupied or sub-divided land, which inhibits any investment in more resilient buildings and often prevents infrastructure and service provision. A high proportion of this are tenants, with very limited capacities to pay for housing – and their landlords have no incentive to invest in better-quality buildings. Most low-income urban dwellers face serious constraints in any possibility of moving to less dangerous sites, because of their need to be close to income-earning opportunities and because of the lack of alternative, well-located, safer sites.

The issue of climate change in Nigeria borders on the fact that current development strategies on poverty reduction tend to

overlook climate change risk. In effect, the existing poverty reduction strategies are continuously challenged by climate change which often time deepens poverty. The country lacks capacity to anticipate and respond to climate change and variability related risk [Gwary, 2008, Kumuyi et al, 2008, Gbadegesin, et al, 2010]. There is no adequate information on seasonal forecast of climate variability to enable preparedness to climate related disaster. Early warning facilities are grossly underutilized.

A cursory look at the situation in Nigeria reveals that most of the recent disasters are weather related and studies have linked these weather related disasters to climate change. Most prominent among these disasters is flooding which has continued to occur more frequently with high intensity in many parts of the country. It is in this regard that the study examines more closely the vulnerability and adaptation to flooding among the victims of rainstorm and flood disasters in Ilorin metropolis. Floods, rainstorms and droughts affect households each year in Ilorin with the poorest being the most vulnerable people in the city and which also contributes to endemic poverty in most parts of Kwara State. Global climate change and anticipated increases in extreme weather events will exacerbate this. Practical methods for minimizing negative impacts of flood can be found by building on actions that families are taking and designing interventions in a way that they accommodate the changing social and natural dynamics. This requires addressing the underlying factors of household vulnerability which is often glossed over or neglected in most disaster relief studies and action. This study hypothesizes that attempts made by households- with or without -the help of external agencies, help them to adapt to flood and rainstorm hazards and to regain livelihoods. One of the benefits of local level case studies of adversely affected communities is the understanding of the intricacies of how households with varying backgrounds deal with multiple stresses; and the ability to recover from economic

and social disequilibria created by the event. This also depends, a lot, on the conditions and dynamics of both human and natural systems which vary in time and space. The findings of case studies like this will assist in designing policies that easily adjust to local realities and prevent the characteristic policy failures.

VULNERABILITY AND ADAPTATION TO EXTREME WEATHER EVENTS: SOME CONCEPTUAL ISSUES

Climate research had paid greater attention to the mechanics of alterations in the environment while a scanty attention had been paid to the vulnerability of the population to the impact produced by the alterations. The study of vulnerability is therefore at its infancy often defined variously and in tandem with the ongoing research. Simply defined vulnerability refers to the capability of the population to be wounded from a perturbation or stress of environmental or socio-economic origins. It is the exposure and susceptibility to harm or damage emanating from environmental conditions like flood, erosion, and other extreme weather events. According to the Intergovernmental panel on Climate Change (IPCC) in its Third Assessment Report (TAR), Vulnerability is defined as the “degree, to which a system is susceptible to or unable to cope with adverse effects of climate change, including climate variability and extremes.... (it is) a function of the character, magnitude and rates of climate variation to which a system is exposed, its sensitivity and its adaptive capacity” [IPCC, 2001 p. 995].

In the context of this paper, vulnerability is understood to mean the tendencies of people to be killed, injured or otherwise harmed as a direct consequence of the occurrence of extreme events like storms or floods on the one hand; or the severity of damages to climate-sensitive livelihood resources on the other. It is also hypothesized that because of the variation in the socio-economic background of people, vulnerability to the impact of extreme

weather events also varies. Apart from this, the nature of cities in developing countries may also precipitate increased vulnerability for the residents in many respects. For instance, not only that the concentration of people and dwellings produces its own risks, but also because of the dangerous conjunction of such residential dwellings and industrial land uses.

Based on the above, the sensitivity and adaptive capacity of human societies are crucial to the degree to which such societies may be vulnerable. By adaptation, we refer to the degree to which adjustments are possible in practice, processes or structures of systems to projected or actual changes in climate. This can be spontaneous or planned in anticipation of changes in conditions [Kasperson and Kasperson, 2001]. Extreme weather conditions present one of the variations to which human and natural systems rarely adapt easily. In other words, spatial and temporal deviations from annual average conditions are common. Social and economic systems like health, transportation and water resource management often adjust to accommodate the deviations from the normal conditions without necessarily causing hardship to the surrounding population of man and animals. It is only during spontaneous and extreme deviations in climate that many of the human and natural subsystems are found wanting and unable to adjust to accommodate the deviations because such changes or their magnitude were not anticipated or planned for.

Thomas et al [2005] developed a conceptual model of the ways in which adaptation and coping with major livelihood disturbances, including climate extremes, may be constructed. According to them, the responses that can occur at the household level are influenced by motivators and barriers to the decision process. This includes aspects of the household's behavioural intention and context, such as available assets (capital and resources), cohesion, values and ambition, social structures, networks and flows of information, altruism,

self-efficacy, and individual experience and knowledge. All these contribute to what actually take place in the 'response space' which is also affected by the locational context in terms of environmental resources and other opportunities, and external socio-political factors.

Identifying what occurs (and why) in the response space is important in terms not only of outcomes (adaptation or coping) but also in terms of the potential to identify whether adaptation has generic characteristics. This would allow the processes of adaptation to be understood and their potential transferability, into the future and to new contexts, to be assessed. It is therefore important to identify critical elements within the response space in terms of how people behave and have learned in respect of recent historical and current climate variability and change, in order to examine their wider relevance to the adaptation process especially among those whose livelihoods are nature based.

Within the conceptual model, individuals and communities have some autonomy to choose adaptation pathways and locate themselves within the adaptation space. The degree to which they are autonomous is, of course, constrained both by the wider economic and political environment but also by antecedent decisions that partly lock them into particular pathways. A key issue then is to identify whether any location or pathway is in any sense superior to any other. This is a normative issue: the success of adaptation clearly involves judgement regarding values and priorities and depends on who is making decisions within the adaptation process. Nevertheless, there are widely accepted notions that successful adaptations should reduce the risks associated with present day and future climate for all involved, and should not reduce the options for future actions. While the assessment of adaptation is inevitably normative in nature, identifying successful and potentially unsustainable adaptations is important both for policy purposes as well as to highlight how the

issue of adaptation can become a crucible for amplifying, or potentially resolving, existing conflicts over development, progress and the allocation of resources.

There are various geographical scales and social agencies involved in the process of adaptation. Individuals may adapt to climate in response to the impact of extreme events. Other adaptations may be undertaken by governments on behalf of society, sometimes in anticipation of change, but again, often in response to specific events. Thus adaptations can be anticipatory and planned (disaster preparedness) or spontaneous and reactive (disaster recovery) [Smit and Pilifosova, 2001].

It is important to consider if it is possible to distinguish coping from adaptation, since to do so may have particular relevance in formulating policies at national and sub-national levels to deal with the impacts of climate change. While policy initiatives by governments may represent adaptations for the sector as a whole, at the local or regional scale, adaptations and their likelihood of adoption will vary depending upon local circumstances. Thus, insights from empirical evidence could make an important contribution to understandings of the various dimensions of adaptation to extreme weather events, especially within disaster prone urban areas.

According to Thomas et al [2005], recent insights into the resilience of social and ecological systems are particularly relevant here. Since resilience is a technical term related to the properties of a system, it can be assessed through indicators that measure, in the context of specific configurations and disturbances, the ability of a system to:

- absorb shocks and retain its basic function;
- self-organise, for example through social institutions and networks; and
- innovate and learn in the face of disturbances.

Elements of resilience theory is taken on board to define successful adaptation as *adaptation that increases social resilience*. The benefits of this approach are that it recognises that there is no single pathway within the adaptation and vulnerability space in our conceptual model, which allows for considerations of variables across scales and contexts. Additionally, it allows the role of governance to be integrated, since a resilient adaptation is likely to require legitimate and inclusive institutions if collective and self-organised (and hence autonomous) actions are to be facilitated in a sustainable manner [Agrawal, 2002].

THE STUDY AREA

Ilorin, the capital city of Kwara State, Nigeria, is the setting for this study. The city is located on latitude 8° 10'N and longitude 4° 35'E marking a divide between the southern forest Zone and the Northern grassland of Nigeria. The vegetation, in most parts, is guinea savanna interspersed by trees of different species. The dominant streams are Asa, Aluko, Okun, Amule, and Agba. The Asa River is of particular influence on the direction of growth of the city. The situation of the city between the dry North and the wet South of Nigeria gave Ilorin the apt description as the "gate way" between the North and the South of the country" [Adedibu, 1980]. The climate is therefore tropical wet and dry characterized by a distinct wet and dry seasons. The mean annual temperature is about 26.80° c with five hours average daily sunshine. The mean annual rainfall is about 125 mm. It is important to note that the above locational and physiographic characteristics possess (sometimes significant) implications for human health on one hand and economic and social development on the other.

Ilorin is a typical traditional African city whose urban history predates colonialism in Nigeria. The city therefore falls into the category of third world cities described as reputed for their dualistic internal structure [Mabogunje, 1968]. The physical development of Ilorin

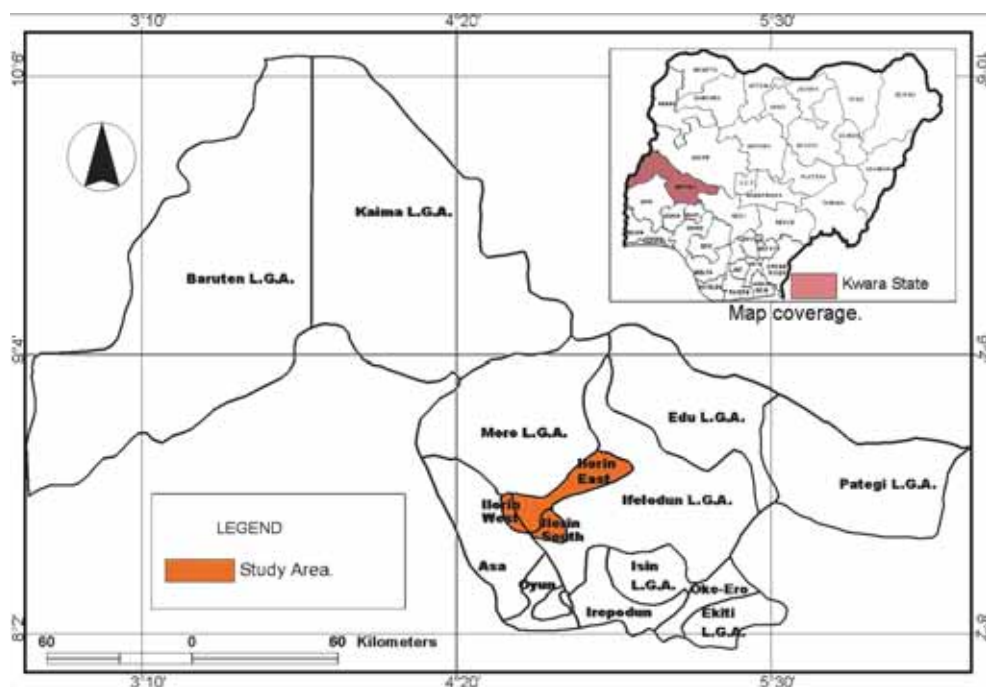


Fig. 2. Map of Kwara State and the Study Area

also translates into significant change in the population of the city. For instance, from 36,300 inhabitants in 1911, Ilorin has a population of about 208,546 in 1963, 532,088 people in 1991 and a projected population of about 765,791 by the year 2006 at the rate of 2.84% annually. The facts of urbanization, development of the modern commercial/industrial economy and the multiplier effects of these factors on natural increase had combined to produce the changes in population described above. Figure 2 is a map of Kwara State showing Ilorin.

Frequent rainstorms and flooding in Ilorin has made it one of the most vulnerable cities in Nigeria in the recent past not only because the number of such incidents had increased in the last few years but also because the severity had translated into extensive damage to properties and the livelihoods of the people.

DATA AND METHODS

In order to study the vulnerability and adaptation methods of flood victims in Ilorin, the study utilized both primary

and secondary data. The secondary data were collected mainly from the National Emergency Management Agency, Kwara State office. The data collected include the details of various disaster incidents in the State between 2002 and 2007. Aside this, data were collected from households that occupied the properties destroyed by rainstorms and floods during the period under review.

For the primary data, the focus was on the disaster victims within the city. According to the Kwara State office of the National Emergency Management Agency (KWEMA), between 2002 and 2007, a total of 30 episodes of flood and/or rainstorm events occurred that affected different parts of Ilorin metropolis. These effects included collapsed buildings and damage to properties. About 4,012 households were reported to have been affected by the incidents [KWEMA, 2007]. Out of these, the researchers were able to trace only 2100 households during the reconnaissance survey for the purpose of this study. The inability to reach all affected households was due to the displacement

that followed rainstorm and flood events. This led to some households changing their residents more than once within a period of five years. Thus, a total of 110 households were sampled, representing 5% of the total number of households that were located during the preliminary survey.

A structured questionnaire was administered to them in addition to oral interviews and on the spot assessment of the victims' houses to determine the extent of damage to properties. The questionnaire elicited information on the socio-economic characteristics of the victims, their opinion of government handling of the situation, their coping mechanisms with the disaster incidents as well as their adaptation measures. The questionnaire also elicits information on how the disaster affected their livelihood systems. Furthermore, the victims were asked about their perception of the causes of frequent rainstorms and flooding incidents, and their understanding of climate changes issues. Data were collected on the characteristics of the victims' houses including age of the building, material used for the construction of the external wall, material for the roof, materials used for the floor, type of dwelling and nature of ownership and neighbourhood characteristics.

Ilorin is traditionally divided into 4 socio-cultural and economic areas: the estates, inner city, frontier native areas and the suburban. These areas are further subdivided into 20 wards. Using the data obtained from NEMA in respect of the number of buildings affected by rainstorm and flooding, the data was organized according to wards from where geographic information systems (GIS) generated map was used to show the spatial variation in flooding/rainstorm severity among the wards. (see figure 3). Furthermore, a multiple linear regression model was tested to see the determinants of the vulnerability of houses to rainstorm and flooding. Specifically, the model was designed to see how housing and neighbourhood characteristics determined the impacts

of rainstorm and flooding on houses. The dependent variable was represented by the number of houses affected by rainstorm and flooding. The independent variables used for the model were the characteristics of the buildings such as age, materials for the wall and the roof etc (these constitute the house quality). Apart from house characteristics, neighbourhood attributes were also used. The neighbourhood attributes were aggregated into one variable called the neighbourhood quality index. Neighbourhood quality index (NQI) was derived from composite of variables which include presence or absence of tarred roads, drainage, solid waste collection system, green areas, odour, health facilities, and pipe borne water. Where a variable is available it is 1 and otherwise 0.

The model was then formulated as follows:

$$\text{NHD (Y)} = b_1 (\text{HTT}) + b_2 (\text{HCB}) + b_3 (\text{HIR}) + b_4 (\text{DT}) + b_5 (\text{NQ})$$

where: Y (NHD) – Number of houses destroyed; X_1 (HTT) – Number of houses older than 20 years; X_2 (HCB) – Number of houses constructed with materials other than concrete – blocks; X_3 (HIR) – Number of houses with inferior roofs; X_4 (DT) – Dwelling; type X_5 (NQI) – neighbourhood quality.

RESULTS AND DISCUSSIONS

Socio-Economic Characteristics of Respondents

The results of the analyses provided in Table 1 shows that males constituted the highest percentage of respondents (74,55%). This is not surprising considering the fact that most households in the city are male headed due largely to socio-cultural and religious factors. More than two thirds of those interviewed are married (86,37%). Also, more than two thirds are above 36 years of age. Specifically, the largest proportions of the respondents (40,0%) are above 50 years of age. Again, this is not surprising considering the fact that most

Table 1. Socio-Economic Characteristics of Respondents

Socio-economic Characteristics		Frequency	Percentage
Sex	Male	82	74.55
	Female	28	25.45
Age	20 and below	–	–
	21–35	28	25.45
	36–50	38	34.55
	Above 50	44	40.00
Marital status	Single	9	8.18
	Married	95	86.37
	Others	6	5.45
Education	No formal education	18	16.37
	Primary	36	32.76
	Secondary	40	36.40
	Tertiary	16	14.57
Occupation	Civil servants	10	9.10
	Farming	31	28.21
	Artisan	42	38.22
	Trading	22	20.02
	Unemployment/retired	5	4.55
Household size	1–3	27	24.57
	4–6	43	39.13
	7–10	28	25.48
	10 and above	12	10.92

of the inhabitants of the core/indigenous areas which are often mostly affected by flooding/rainstorm are old people. With respect to the level of education obtained, 16,37% have no formal education while only 14,57% have tertiary education. Most of the respondents are artisans (38,22%), 28,21% farmers and another 20,02% are traders. It is clear from the results that only 9,10% of the respondents are engaged in the formal sector. This result is very peculiar to situations obtained in many similar neighbourhoods in the Nigerian urban areas. With respect to the household size, close to 80% of the respondents have more than 4 people in the household.

Spatial Pattern of Flooding/Rainstorm Incidents in Ilorin

An analysis of the Data obtained from NEMA office shows that the impacts of the

flooding/rainstorm disaster incidents were more in the traditional, core areas of the city going by the number of properties damaged. Figure 3 is a map of Ilorin showing the severity of the disaster incidents.

It should be noted that the traditional, core areas of the city are characterised by high population and the people in these areas are most at risk of all environmental emergencies. This is because basic infrastructures are either not available or old and weak. The houses are also too old or are made of low quality materials. The existing situation has increased the anxiety on the part of the people that future incidents will continue to have higher impacts. The next section which discusses the characteristics of the affected buildings from data collected from the field further confirm the fact that most of the buildings in most parts of the city

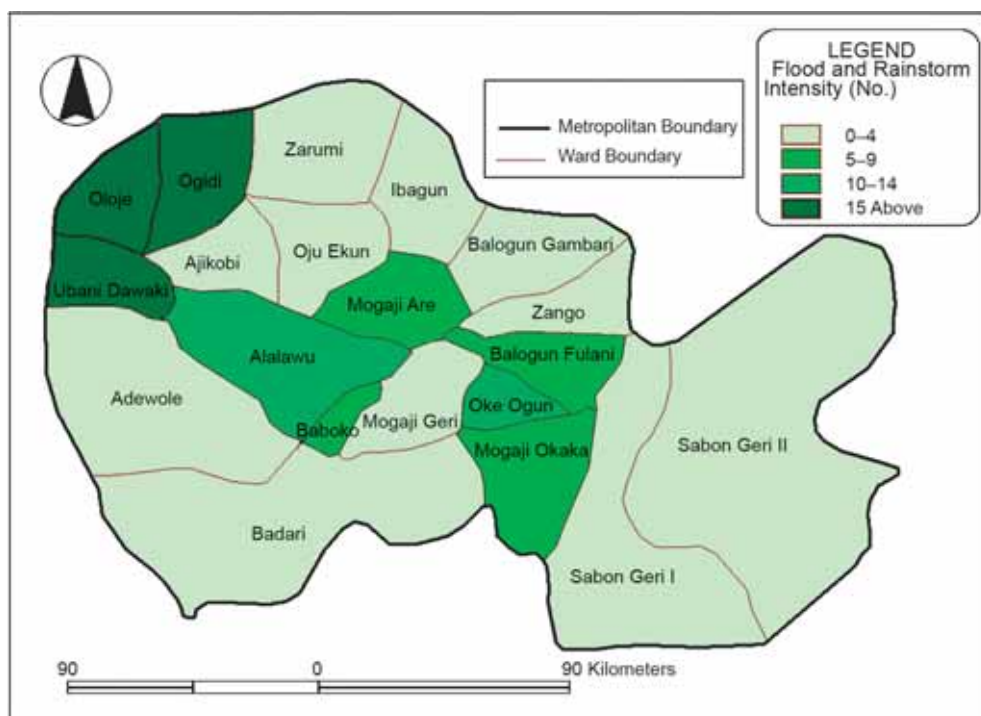


Fig. 3. Map of Ilorin Metropolis showing the Severity of Floods and Rainstorm Intensity

especially the core, indigenous areas cannot withstand rainstorm or severe flooding whenever they occur.

Characteristics of Affected Buildings

Data on the attributes of respondents' houses were collected. This data becomes important considering the fact that the structure of a building directly affects its resistance to rainstorm and flooding. A random survey of the buildings in the most affected areas shows that the houses are not of very good materials and hence they are highly vulnerable to various kinds of disasters.

The results presented in Table 2 shows that more than a half (60%) of the houses are more than 30 years of age, more than one third (37,3%) constructed with mud bricks. About 64,6% roofed with metal sheets which have turned brownish and fragile over the years. More than two third of the houses have their floor made with earthen floor, out of which about 12,7% are not plastered at all. The houses are mostly multi family

house (35,5%). The implication of this is that more people are exposed to risks when ever disasters strike in the area, especially the core/indigenous areas.

The result of the multiple linear regression model tested to see the determinants of the vulnerability of houses to rainstorm and flooding shows that the house characteristics and neighbourhood quality contribute significantly to vulnerability to rainstorm and flooding. The 'r' value obtained for the model is 0,65 while the R^2 is 0,43 (Table 3). This result is interpreted to mean that the independent variables contribute 43% to the explanation of the determinants of vulnerability of houses to flooding. Furthermore, the unstandardized regression coefficients shows that HTT (age of building) contributed most to this explanation among the independent variables.

Impact of Flooding on Livelihood Systems

Flooding and firestorm disasters, apart from causing destruction to lives and properties

Table 2. Characteristics of Affected Buildings

Characteristics		Frequency	Percentage
Age of building (years)	1–10	4	3.63
	11–20	12	10.92
	21–30	28	25.48
	31–40	51	46.41
	42 and above	15	13.65
Materials for External wall	Bricks	65	59.15
	Concrete plates	3	2.73
	Mud bricks	41	37.31
	Wood logs	1	0.91
Materials for the roof	Asbestos sheets	10	9.10
	Metal sheets	71	64.61
	Tiles	2	1.82
	Mood thatch	17	15.47
Material for the floor	Tile	12	10.92
	Concrete	18	16.38
	Plastered earthen floor	66	60.06
	Unplastered earthen floor	14	12.74
Type of dwelling	Detached house	10	9.10
	Multi family house	39	35.49
	Separate apartment	7	6.37
	Rooms in a large dwell	36	32.76
	Others	18	16.38
Nature of ownership	Owner occupied	43	39.13
	Family owned	45	40.95
	Rented house	18	16.38
	Others	4	3.64

Source: Authors' Analysis.

Table 3. Coefficients*

Model	Unstandardized Coefficientns		Standardized Coefficientns	t	Sig.
	B	Std. Error	Beta		
1 (Coystant)	6.595	6.058		1.089	0.295
VAR00001 HTT	0.251	0.863	0.091	0.291	0.775
VAR00002 HCB	5.927E-02	0.494	0.029	0.120	0.906
VAR00003 HIR	−0.592	0.793	−0.201	−0.746	0.468
VAR00004 DT	8.001E-02	0.669	0.030	0.120	0.907
VAR00006 NQ	−6.625	2.408	−0.594	−2.751	0.016

* Dependent Variable: VAR00007 NHD.

can also cause significant damage to livelihood systems of the victims. This has been the case with the victims which this study focused on. The damage or destruction to livelihoods systems would be seen to have compounded the existing poverty situation among the victims. When asked the various ways by which the flooding and rainstorm disasters have eroded their livelihood systems, pauperisation and health problems appear to be the major dimension. For instance, as lamented by some respondents, the incidents generally caused destruction of electricity in some areas for months, trading, one of the major occupation of the victims staled, and crops washed away on farms, especially among those in the suburban. It should be noted that when electricity supply is unavailable for some time, it slows down economic activities among the traders and the artisans which, incidentally, constituted the highest proportions of those affected. Furthermore, the disasters are associated with a number of health problems including bodily injuries as well as the attendant psychological trauma. According to one of the victims, "when one's health is affected by disaster incidents, it becomes difficult, if not impossible, to continue with one's means of livelihood". According to him, this is the singular most worrisome aspect of disaster impact". The post disaster adjustment would have been easier if relief comes from government and non-governmental organisations on time.

A number of women in the inner city and Frontier Native areas depend on irrigated vegetable farming around the flood plains of Asa, Aluko and Amule- the three dominant

streams that flow in most parts of the metropolis. During flood events, vegetable farms are washed away and the land remain flooded for a long time after. Women are rendered unemployed for upwards of three months when they can start all over. To worsen this situation, poor urban women's economy is not diversified and thus entrenching the regime of poverty.

Coping Mechanisms Employed by Victims

Poor communities can be especially vulnerable, in particular those concentrated in high-risk areas. They tend to have more limited adaptive capacities, and are more dependent on climate-sensitive resources such as local water and food supplies (see Satterthwaite et al, 2007). The victims were asked how they coped with the immediate impact of the flooding/rainstorm disaster and the adjustment process. The results presented in Table 4 shows that by and large, support from friends and relatives and personal savings accounted for the way large proportion of the victims cope with the immediate impacts of the disaster. Even though government support came for most of them, many of the victims said the support did not come on time and it did not measure any closer to the degree of impacts suffered by the victims. This calls to question the level of disaster response in Nigeria. It is an accepted fact that the agency charged with disaster management in Nigeria (NEMA) is incapable of responding promptly and managing the various disasters that had occurred in Nigeria in recent years. A major problem has been in the areas of funding and lack of modern equipment to respond

Table 4: Coping Mechanisms employed by Victims

	Frequency*	Percent
Personal savings	29	23.7
Support from friends and relatives	50	41.00
Borrowing from local money lenders	11	9.01
Borrowing from banks	6	4.91
Government donations	26	21.31

* Multiple sources of coping mentioned by respondents.

to disasters in the country. According to some of the victims, many of them did not get relief materials until after six months especially those that had to do with materials to repair or rebuild damaged properties. The coping mechanisms employed by victims s as presented in Table 4

Adaptation Measures to Rainstorm and Flooding Disasters in Ilorin

Given the existing low level of knowledge of victims about climate change issues, it became difficult to elicit information from them on how to adapt to the problems. Interviews with the victims on adaptations measures they would need or are currently using reveals that two broad measures are required. These are the short term and the long term measures. Immediate, short term measures include improvement in the waste collection system and in the core areas, introduction of waste collection system to avoid drainage blockage. Secondly, drainage channels in the modern parts of the city have to be opened to allow free flow of water during heavy rainfall. But in the core, indigenous areas, drainage channels would have to be constructed because they are currently non-existent.

Furthermore, some of the victims especially those who are traders and artisans have decided not to keep too much of their goods in stock during the raining season to avoid heavy losses. Some also have decided to imbibe banking culture by keeping their money in the banks. There is, however, no mention of insurance among the respondents. It's something that is strange to more than 70% of them.

The long term measures proposed by the victims include reinforcement of the houses in the indigenous areas or complete rebuilding of some of the houses. However, when asked if the victims would be willing to relocate from their present areas especially those in the worse hit areas, many of them said that they have never contemplated such as move. This was especially true among the old.

As easy as some of these adaptation measures may seem, the existing level of poverty may hinder any of such measures. This is why government at the state and local level must come in. government need to put in place measures to reduce the remote factors that exacerbate the intensity and impacts of flooding and rainstorm. Such measures include construction of drainage channels in all parts of the city, improved waste collection system in the city. The government would need to support both the victims and the non victims in reinforcing the existing weak structures in most parts of the city and especially in the indigenous area. But more importantly, there is need for government to enforce building regulations and to improve on city governance.

CONCLUSION

This study brings out the important issue of vulnerability, coping and adaptation to climate change induced disasters among the urban poor. It examined in some detail the strategies adopted by poor neighbourhoods as disasters impact on their highly complex livelihood systems and the sequence of responses which they employ over time as they struggle to cope.

The study revealed that the indigenous coping mechanisms employed by the poor may become less effective as increasingly fragile livelihood systems struggle to withstand disaster shocks. Also, many of these long-term trends are rendering indigenous coping strategies less and less effective and thus are increasing the vulnerability of the poor.

It seems increasingly accepted (although not consistently implemented) that disasters shouldn't be dealt with through humanitarian relief interventions alone. There is some evidence to support the argument that disaster management response in the city, just like in other areas in Nigeria, should shift away from this traditional response approach to focus increasingly on addressing the causes of vulnerability in

order to mitigate the effects of disaster. However, the approach tends to address only the visible signs of vulnerability, such as poor access to services, and generally fails to make a deeper analysis based on the maintenance of sustainable livelihoods by vulnerable people. Vulnerability is seen as a physical problem which can be addressed mainly through technical solutions such as infrastructure development which may not even be provided at the appropriate time. However, this approach generally fails to take into account the views, capacities, knowledge and priorities of local people and is thus limited in effectiveness in truly reducing vulnerability.

The result of the study is expected to be useful in designing appropriate institutional interventions capable of transiting victims from being painful victims to developing adaptive capacity to live with recurring floods in Nigeria. Most studies indicate, with sufficient evidence, that climate will

continue to change with far reaching implications on the environment and human livelihood.

The climate change and variability are likely to worsen the prospects for poverty eradication unless action is taken to become response-capable. This requires a focus on reducing vulnerability, achieving equitable growth and improving the governance and institutional context in which poor people live. Strategies to reduce vulnerability should be rooted in vulnerability analysis and greater understanding of both household-level and macro response options that are available to decrease the poor's exposure to climate risk. Increasing the response-capability of Nigeria will require information on seasonal forecast to enable the preparedness to climate variability as well as longer term climate prediction data to ensure that strategies to reduce vulnerability also reflect the underlying longer-term climate trends. ■

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SCIENCE AND TECHNOLOGY FORESIGHT 2030 IN RUSSIA: ENVIRONMENTAL MANAGEMENT

Science and Technology (S & T) foresight in Russia is quite a new phenomenon. If in the UK, for example, the first cycle of S & T foresight was held in 1994; in Russia it was initiated by the Ministry of Education and Science only in 2007. Now, the third cycle of S & T foresight that targets development in 2030 is being implemented. Stakeholders consider its results the basis for the forecast integration in strategic management of development of the Russian Federation. The third cycle of foresight focuses on six priority areas of scientific and technological development of Russia, i.e. energy efficiency, medicine, transport, new materials, information and communication technology, and environmental management. In 2011, a network of S & T Foresight Centers on these areas has been established at the leading Russian universities to provide expert support of forecast activities. A Foresight Center on environmental management is functioning at the Lomonosov Moscow State University (MSU). Its activities are connected with the platform "Technologies of Environmental Development."

The main directions of S & T forecasting in the area of environmental management are defined by three key critical technologies (the List of critical technologies was approved by the Presidential Decree of July 7, 2011):

- Monitoring and forecasting of the state of the environment, prevention and mitigation of its pollution;
- Exploration, mining, and development of mineral deposits;

- Prevention and mitigation of natural and technogenic emergencies.

The MSU Foresight Center is the coordinator of the network of the leading Russian universities that serve as the centers of competences in the key critical technologies. The network includes Tomsk State University, I. Kant Baltic Federal University, Belgorod State University, Russian State Hydrometeorological University, Kazanskiy Federal University, Perm State University, and some others, 13 universities in total. The network universities have close contacts with other higher educational institutions, scientific organizations, and enterprises of the real sector of the economy. The main activities within the MSU foresight network are shown in the Figure 1.

The major objectives of the system of national forecasting in the area of environmental management are:

- Analysis of global and national challenges and trends, and windows of opportunities for S & T;
- Description of the most perspective thematic areas and their technology components that may be the drivers for the emergence of new market segments;
- Identification and analysis of perspective markets and niches of products and services that will be most promising for development in the future, in Russia (alone or in cooperation);
- Identification of S & T areas where Russia has leading or equal positions with the

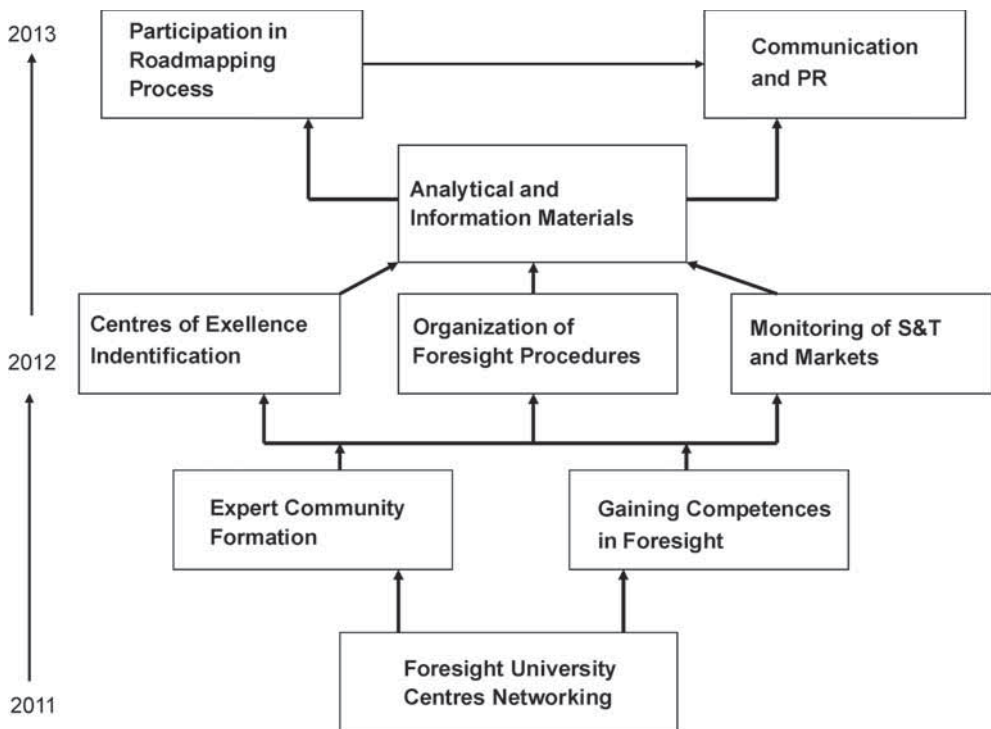


Fig. 1. The main activities of the MSU Foresight Center on environmental management

developed countries, as well as of “white spots” or lags in some areas;

- Recommendations on the prospects for cooperation in the S & T area.

Because the Foresight methodology requires the involvement of experts and the stakeholders in the foresight process, the issues of the expert community formation are among the most important positions for the MSU Center. Now, the national expert network includes more than 250 institutions and companies and more than 350 leading experts. During 2011–2012, the expert community has participated in different foresight procedures, including expert panels, brainstorming, surveys, workshops, etc. Approximately 300 experts were invited to participate in research activities.

One of the outcomes of the above-mentioned activities was the identification

and ranking of global challenges and the most important, emerging trends related to the environment in Russia. They have to be identified from the policymakers’ perspective in order to support development of relevant strategies. Russia’s ability to manage challenges and emerging trends will shape the future of scientific and technological development in the area of environmental management. The list of 38 most urgent economic, social, technological, and environmental challenges was developed based on analysis of various Russian Strategies and State Programs. Numerous international forecasts and foresight studies done by UNEP, OECD, and European Environmental Agency were also analyzed. Most crucial trends for Russia that open windows of opportunities are as follows: greening of the economy, accelerated development of the Arctic, oil and natural gas production growth, development of environmentally safe waste disposal technologies, and

development of supercomputing technologies and information storage systems for modeling and prediction of climate and ecosystems. At the same time, a number of trends, according to the experts, create significant threats to Russia in the near future, including: increased morbidity and mortality from air pollution, increase of the urban population, climate change, biodiversity losses, etc. Climate change is a threat to Russia in the short term; however in the medium term, it can be either a threat or present new opportunities. Despite the fact that threats and windows of opportunities may appear close to 2020,

a package of response measures must be undertaken now. This is an important challenge for science, technology, and innovation policies implemented by the Ministry of Science and Education of the Russian Federation.

The MSU Foresight Center, together with the network of the leading universities, will serve as the foundation for the emerging system of national forecasting in the area of sustainable environmental management.

Nina N. Alekseeva

INSTRUCTIONS FOR AUTHORS CONTRIBUTING TO “GEOGRAPHY, ENVIRONMENT, SUSTAINABILITY”

AIMS AND SCOPE OF THE JOURNAL

The scientific English language journal “GEOGRAPHY, ENVIRONMENT, SUSTAINABILITY” aims at informing and covering the results of research and global achievements in the sphere of geography, environmental conservation and sustainable development in the changing world. Publications of the journal are aimed at foreign and Russian scientists – geographers, ecologists, specialists in environmental conservation, natural resource use, education for sustainable development, GIS technology, cartography, social and political geography etc. Publications that are interdisciplinary, theoretical and methodological are particularly welcome, as well as those dealing with field studies in the sphere of environmental science.

Among the main thematic sections of the journal there are basics of geography and environmental science; fundamentals of sustainable development; environmental management; environment and natural resources; human (economic and social) geography; global and regional environmental and climate change; environmental regional planning; sustainable regional development; applied geographical and environmental studies; geoinformatics and environmental mapping; oil and gas exploration and environmental problems; nature conservation and biodiversity; environment and health; education for sustainable development.

GENERAL GUIDELINES

1. Authors are encouraged to submit high-quality, original work: scientific papers according to the scope of the Journal, reviews (only solicited) and brief articles. Earlier published materials are accepted under the decision of the Editorial Board.

2. Papers are accepted in English. Either British or American English spelling and punctuation may be used. Papers in French are accepted under the decision of the Editorial Board.

3. All authors of an article are asked to indicate their **names** (with one forename in full for each author, other forenames being given as initials followed by the surname) and the name and full postal address (including postal code) of the **establishment(s)** where the work was done. If there is more than one institution involved in the work, authors' names should be linked to the appropriate institutions by the use of 1, 2, 3 etc superscript. **Telephone and fax numbers and e-mail addresses** of the authors could be published as well. One author should be identified as a **Corresponding Author**. The e-mail address of the corresponding author will be published, unless requested otherwise.

4. The GES Journal style is to include information about the author(s) of an article. Therefore we encourage the authors to submit their photos and short CVs.

5. The optimum size of a manuscript is about 3 000–5 000 words. Under the decision (or request) of the Editorial Board methodological and problem articles or reviews up to 8 000–10 000 words long can be accepted.

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7. We encourage authors to list three potential expert reviewers in their field. The Editorial Board will view these names as suggestions only. All papers are reviewed by at least two reviewers selected from names suggested by authors, a list of reviewers maintained by GES, and other experts identified by the associate editors. Names of the selected reviewers are not disclosed to authors. The reviewers’ comments are sent to authors for consideration.

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Before preparing papers, authors should consult a current issue of the journal at <http://www.geogr.msu.ru/GESJournal/index.php> to make themselves familiar with the general format, layout of tables, citation of references etc.

1. Manuscript should be compiled in the following **order**: authors names; authors affiliations and contacts; title; abstract; key words; main text; acknowledgments; appendices (as appropriate); references; authors (brief CV and photo)

2. The **title** should be concise but informative to the general reader. The **abstract** should briefly summarize, in one paragraph (up to 1,500 characters), the general problem and objectives, the results obtained, and the implications. Up to six **keywords**, of which at least three do not appear in the title, should be provided.

3. The **main body** of the paper should be divided into: (a) **introduction**; (b) **materials and methods**; (c) **results**; (d) **discussion**; (e) **conclusion**; (f) **acknowledgements**; (g) **numbered references**. It is often an advantage to combine (c) and (d) with gains of conciseness and clarity. The next-level subdivisions are possible for (c) and (d) sections or their combination.

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