European Russia and Byelorus

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Abstract

The processes of sheet, rill and gully erosion on slopes of European Russia and Byelorus are controlled by landform, the vegetation cover, melt water and rainfall erosivity, soil erodibility and land-use. The combination of land-use history and variations in factors produced a pattern of erosion that is unique to this area. Calculations show that the total volume of soil loss from slopes in European Russia during 18- 20th centuries amounts to 70.5 10^9 m^3 and in Byelorus - to 4.3 10^9 m^3. Annual soil loss in European Russia in 1970-80s was ~ 420 million tonnes from 88.7 10^6 ha of arable land and in Byelorus ~ 20 million tonnes from 5.8 10^6 ha of arable land. The gully net was formed during the last 300-400 years by 1,045,600 gullies with a volume of 3.5 billion m^3 in European Russia and by 14,500 gullies with a volume of 0.054 km^3 in Byelorus. About 94% of eroded material was deposited in the river net, mainly in small river floodplains and channels. The contemporary land conservation policy in the both countries is uncertain, and a new body of laws needs to be designed to promote farming techniques, which conserve soils and water resources

Key words: sheet and rill erosion; gully erosion; river channel sedimentation; river bank erosion; tillage erosion; soil loss with the harvest; reservoir bank erosion; wind erosion; land conservation policy; European Russia; Byelorus.

1. Introduction

The plains and uplands of the European part of the Russian Federation (Russia) and the Republic of Byelorus' (Byelorus), with an area of 4.03 (3.82 and 0.21) 10^6 km^2

are surrounded by the Ural Mountains in the east; the Barents Sea in the north; Finland, the Baltic States, Poland and the Ukraine in the west; and the Azov and Black Sea, Caucasian Mountains and Caspian Sea in the south (Figure 1). The processes of erosion and sedimentation are most clearly manifested in (1) sheet and rill erosion on slopes; (2) gully erosion and (3) deposition of sediments in dry valleys and river systems. These processes are controlled by topography, soil erodibility, melt water and rainfall erosivity, vegetation cover and land-use. The combination of land-use history and variations in the above biophysical factors produced a history and pattern of erosion that is unique to this area. In this pattern, the influence of geographical zoning is clearly evident, and is expressed in changes of the climatic and landscape conditions over the territory, in the latitudinal extent of vegetation and soil zones and in socio-economic conditions. The development of intensive agriculture, beginning in the 15-16th centuries, first occurred in the forest zone, then in the forest steppe and then the steppe zone.

1.1. Landforms

Three main latitudinal belts with different terrain types are characteristic of the territory. The northern belt of fresh glacial and fluvioglacial relief occupies the northern megaslope of the Russian Plain (Onega, Severnaya Dvina, Mezen' and Pechora River basins) and the Upper Volga basin. Here narrow chains of uplands separate broad lowlands. Due to the deep seasonal soil freezing and generally high soil moisture content, arable lands are mainly situated on the steeper drained slopes with mean lengths of 130-380 m and inclination of 2-5° (up to 9-10°). The middle belt of the old glacial and fluvial relief consists of a sequence of undulating lowlands and uplands, from the Poles'ye and Pridneprovskaya lowlands in the west to Middle Russian upland and Oksko-Donskaya lowland in the centre and the Privolzgskaya upland and Zavolzhskaya lowland in the east. Here agricultural selectivity of relief is less marked: only the steepest slopes are not ploughed. Therefore the difference between arable fields in the lowlands (inclination ~1-2°, slope length 200-300 m) and in the uplands (inclination 4-8°, length ~400 m) is pronounced. The southern belt of fluvial and coastal relief has a similar structure and consists of the Asov-Kuban' lowland in the west and Prikaspiyskaya lowland in the east, separated by the Stavropol' upland. Here the slope inclination of arable land is extremely varied: 0.5°

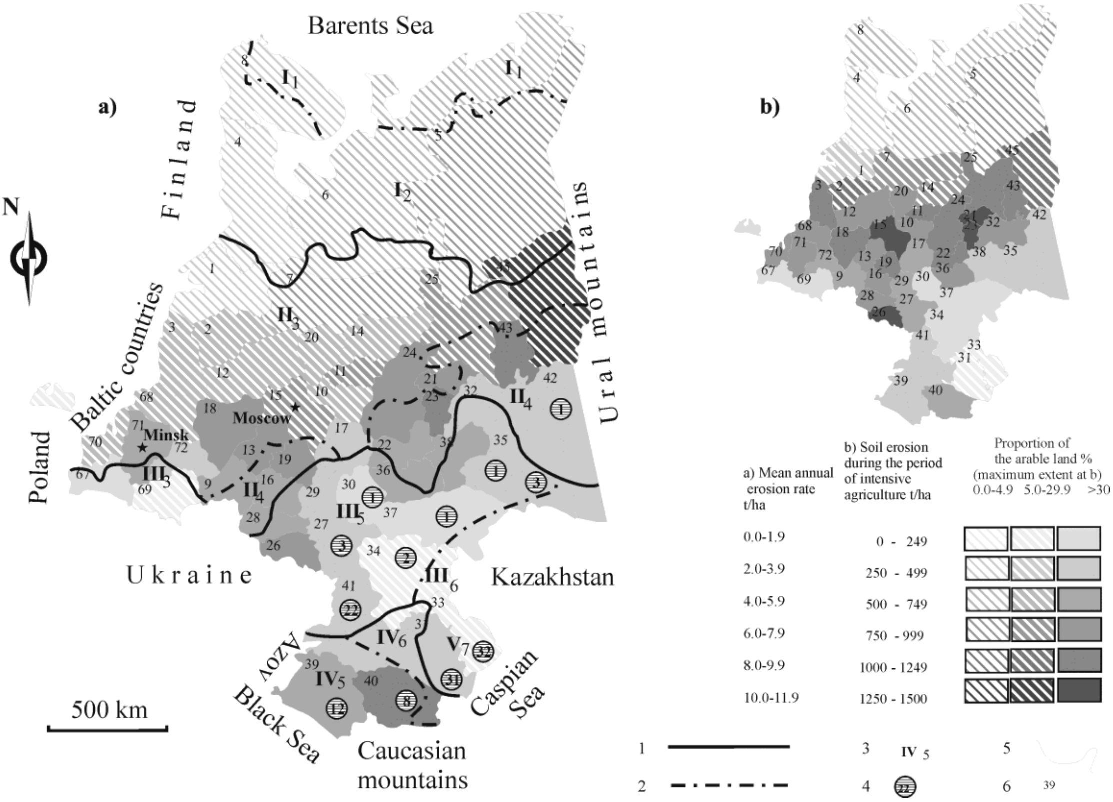

Fig. 1 (a) Contemporary (calculated) soil erosion rates in European Russia and Byelorus and (b) soil loss (calculated) during the period of intensive agriculture. Key: 1 – boundaries between natural erosion zones; 2 – boundaries between main regions of man-induced erosion; 3 – zone and region indices, (I) melt-water erosion; (II) melt-water and rainfall erosion; (III) mainly rainfall erosion; (IV) rainfall erosion without snow melt; (V) occasional erosion; and (1) reindeer breeding; (2) sporadic farming; (3) mixed farming - cultivation and stock-raising, with highly selective land-use; (4) intensive tillage with low selectivity; (5) land fully exploited for cultivation; (6) tillage and grazing; (7) grazing and sporadic cultivation ; 4 – percent of district area, affected by wind erosion; 5 – administrative district boundaries; 6 – district indices as in Table 1.

in the lowlands and 5° in the uplands, but the slope length is more uniform: 600-650 m. All these morphological units (and their smaller elements) are characterised by a typical probability density functions and mean values of the Universal Soil Loss Equation (USLE) LS factor: in uplands it ranges from 1.5 to 2.5 and up to 3, in lowlands it usually ranges from 0.4 to 0.75, and lowest value is 0.25 (Litvin et al., 2003).

1.2. Soil erodibility

European Russia is a classical area of the latitudinal extent of soil zones, first discovered by Dokuchaev (1883). The northernmost is the zone of tundra gley and gley-illuvial soils, which grades to podzols under the coniferous forests of the northern and middle taiga and sod-podzols of the southern taiga. Further south the zone of grey forest soils was formed under broad-leaved forests and a broad zone of chernozems corresponds to the forest-steppe and typical steppe. In the dry steppe dark-brown (chestnut) soils are predominant. Grey-brown and light-grey-brown soils occupy the southernmost desert zone.

Soils differ in their susceptibility to erosion, determined by their mechanical composition, organic matter content, structure and rate of formation. A commonly used index of erodibility is the USLE K factor. Resistance to erosion increases from north to south from podzols to grey forest soils and chernozems, and then decreases in the dark-brown soils and desert and semi-desert soils. Well-structured chernozems and dark-grey forest soils with a high organic matter content and loamy texture are most resistant (K as low as 0.11-0.16 t ha^{-1} per erosivity unit), the least resistant being podzols, sod-podzols, desert grey-brown and light-grey-brown soils (K factor reaches 0.46-0.53 t ha^{-1} per erosivity unit). The same trend was found for the formation rate of humus (A) horizons: it is 0.1-0.2 mm yr^{-1} for podzols, 0.2- 0.3 mm yr^{-1} for sod-podzols, 0.35-0.4 mm yr^{-1} for grey forest soils, 0.4-0.45 mm yr^{-1} for chernozems, 0.2-0.3 mm yr^{-1} for dark-brown soils and 0.1 mm yr^{-1} for light-brown and solodic soils (Gennadiev et al., 1987).

1.3 Climatic factors affecting erosivity

Climate is temperate-continental with a long severe winter and short summer. The main climatic factors influencing water erosion are snow-melt runoff and rainfall. The period of snowfall extends from mid-October until early May in the north, and from late December until late February in the south. The depth of water flow during the snowmelt period is determined by the amount of water in the snow at the start of the melt and by the runoff coefficient. The late-winter water content of snow is greatest in north-eastern European Russia, decreasing towards the south and west. In the south, snow cover is absent in some years. The value of the runoff coefficient in the thaw period depends on soil saturation and the extent of soil freezing. High runoff coefficient values in the northern, north-western and central regions can be explained by the soils being moist in autumn and deeply frozen in winter. The decrease in the coefficient eastwards is the result of lower early winter soil moisture contents, despite the extent of freezing. Towards the south there is a decrease in both the soil moisture content and the degree of freezing. Due to the similar spatial distribution of the main factors determining runoff during the melt, runoff in European Russia decreases rapidly from north to south (from 200-220 mm to 10-20 mm) and from the central regions to the east and west.

Runoff during the period of summer rains is determined by the amount of rainfall and the runoff coefficient. Runoff coefficient value depends on slope morphology, vegetation cover and soil infiltration capacity, varying within broad limits over the territory. Rainfall energy and its erosive capacity, expressed by the rain erosivity (R) of the USLE, are closely correlated with rainfall amount. The distribution of rainfall, and that of R, is variable over European Russia, but it has a tendency to increase from north to south and from east to west. The proportion of rainfall in total precipitation is ~ 50-70% in the north and up to 90% in the south of the territory. The proportion of melt water in total runoff is much greater than that of the rain water, because runoff coefficients during the snow thaw period are higher than in the rest of the year.

1.4 Vegetation Cover

In its natural state the vegetation cover of European Russia and Byelorus was in all areas dense enough for erosion to be slow. Under present conditions in the northern part of the territory, where the natural plant cover of tundra and taiga is mostly undisturbed, erosion rates remain very low. In the agricultural areas, vegetation cover is almost entirely determined by land use. Similarities of crop rotation and cultivation systems in various zones have substantially reduced regional variability of this changeable factor. In European Russia and Byelorus as a whole, the protective role of vegetation decreases towards the south and south-west, with a diminishing proportion of perennial grasses in the crop-rotation system and a higher proportion of repeated sowing of inter-tilled crops. In the taiga zone, crop vegetation cover in the fields reduces erosion by 40-70% during the spring snow melt and by 75-85% during summer rains. In the mixed and deciduous forest zone this reduction is 20-60% and 70-75%; and in the steppe - 15-20% and 60-70%, respectively.

1.5 Land Use

Agriculture became a permanent part of the economy of the Eastern Slavs towards the late 15th century, as the Muscovite State gained control of most of European Russia. Clearing of forests in the southern half of the forest zone then took place. In the 16th century new territories were opened up and settlement established in the Central Chernozem, central Volga and central pre-Ural regions. An intensive agriculture developed, with a fallow system in the steppe region, and clearing-burning and fallow systems in the forest-steppe and forest zones (Krokhalev 1960). At the beginning of the 18th century the area of arable land increased rapidly. A three-field system (winter wheat, summer crops and fallow) began to be used in the central regions of European Russia and the area of industrial crops (such as flax) began to increase, although it still remained very small. The most favourable arable land was largely found on the southern slopes of morainic hills with gradients of 2-4° directly adjoining river valleys, along which most settlement developed. Ploughing was restricted to the hillslopes. As a result, the length of the fields did not exceed 150-220 m. At the end of 18th century the settlement of the southern and south-eastern parts of the territory began. As people moved southward into a region with greater local relief, they began to cultivate slightly longer and steeper fields: slopes of 5-7° were cultivated, often 300-400 m long. Ploughing along (up and down) the slopes was retained , as in the forest zone, and promoted gully formation (Sobolev, 1948).

Reliable agricultural data for Russia were obtained during a General Survey in the late 18th century (Tsvetkov, 1957). This period saw a gradual decrease in arable fertility as increasing production of cereals for export displaced cattle rearing. The three-field system of rotation was at this time applied over most of the territory. In the first half of the 19th century, different agricultural systems began to be used. In the Yaroslavl' and Moscow districts, for example, a four-field crop rotation system (fallow, winter wheat, clover, and summer crops) was introduced beginning from the 1820s. A crop-rotation system without fallow was used in the western regions (Byelorus). Most landowners, however, retained the traditional three-field system. A commercial cattle rearing was predominantly retained in the south and southeast. .

After the abolition of serfdom in 1861, radical changes occurred in the agriculture of Russia. There was a marked increase in crop specialisation, and only the north-east retained the clearing-burning system for cereals. Intensive ploughing began in the southeast and south in the Stavropol' steppes, with the fallow system retained. Flax was now sown over a wide region in the northwest and Upper Volga region as far as Nizhniy Novgorod, being incorporated in the multi-field rotation (fallow-rye-oats-2 year grass-flax-oats). In the rest of the territory, outside the chernozem zone, eight-field rotations were used, in which cereals alternated with fallow, grass and potatoes. Western regions now began to specialise in beet production, which was included in a ten-field rotation or in an improved cereal rotation (fallow-winter cereals-beet-summer cereals). The ploughed area in southern forest and forest-steppe zones of European Russia reached its maximum in late 19th century (Table 1). In the grain-producing areas of the Central Chernozem zone, the crop rotation was often broken and grains sown in three or four consecutive years. It was also a period of increase in numbers of land users who owned small fields: 60% of peasants owned land with an area <10 ha. At this time in both the forest and forest-steppe zones steep slopes of dry valleys, unsuitable for cultivation, were ploughed. Narrow strips along the slope represented the plots of land. These strips were separated from each other by deep plough lines, which concentrated flow and promoted gully formation. The length of the ploughed parts of slopes did not exceed 100-150 m in the forest zone, 200-250 m in the forest steppe and 300-350 m in the steppe.

The area of arable land was reduced during World War I, followed by a period of significant private involvement in agriculture during the 1920s. This period ended with general collectivisation beginning in 1928. Crop rotations changed to multi-field, somewhat improving soil protection against erosion by increasing vegetation cover. The area of cereal crops decreased from 80-85% to 70-75%, as industrial (mainly sunflower and sugar beet) and fodder crops increased. Field sizes increased because the area of fallow land was reduced, and tractors were introduced. Development began in the virgin lands of the lower Volga, in the pre-Urals, the pre-Caucasus and the lower Don River basin.

During World War II the area under crops was again everywhere reduced, by a factor of not less than three. By the late 1950s the area of crops had been restored, due to the use of tractors, combine harvesters and other techniques. A change in the structural and hydrological properties of soils began at this time, resulting particularly from the increased loading by machines, and causing increased runoff and erosion. After the 1950s all arable land in the steppe zone of the territory was used, with the last increase in ploughed area coming about by cultivating floodplains, which had previously been used for pastures. The near doubling of the weight and size of tractors continued the process of making tilled soils more susceptible to erosion. Some reduction in the area of ploughed land in the forest zone and forest steppe zone occurred in the 20th century, as the most eroded areas were excluded from cultivation and some lands were used for urban development and mining.

The 1970-80s were characterised by year-to-year variations of only 1-2% in the area of cultivation. Disc ploughing of 10-15% of the Chernozem zone increased the resistance of these soils to erosion. Outside this zone, the extensive use of grain-fodder systems with 30-40% perennial grasses in the rotation of these crops also increased resistance to erosion by increasing vegetation cover.

2. Spatial distribution of sheet and rill erosion

2.1. Contemporary processes

The spatial distribution of soil loss in an area with such diverse climate, soil and relief as European Russia and Byelorus is extremely complicated (Litvin *et al*., 2003). Substantial changes in the climatic parameters of the area, such as precipitation and the proportion of rain in relation to snow, produce various zonal combinations of fundamentally different forms of erosion: melt-water erosion and rainfall erosion (Figure 1). In the north lies zone I of melt-water erosion and further south zone II of melt-water and rainfall erosion. At its northern limit the severity of soil loss from both types of erosion is approximately equal. At the southern limit of zone II the rate of melt water erosion is roughly equal to the rate of natural soil formation. The northern limit of zone III, in which rainfall erosion predominates, corresponds to the limit of the area with irregular snow cover. Further south, in zone IV melt water erosion rarely occurs, and the proportion of rainfall erosion is much higher. The southernmost zone V of occasional rainfall erosion is a region where erosion by water is very rare and extremely short-lived.

Agricultural land-use represents another basis for zonation of the erosion status. The distribution and extent of agriculture, the proportion of tillage and the relation between pasture and arable land determine erosion severity. For example, in region 1 with its reindeer pastures, water erosion occurs only within highly disturbed oil and gas fields, and the pasture itself is subjected mainly to wind erosion if overgrazed. In patchy farming region 2, erosion severity on cultivated slopes is substantial, but the total soil loss is small because arable land comprises only a few percent of an area, which is mostly forest or tundra. Soils in the north generally receive excessive moisture. Therefore the well-drained land patches on rather steep slopes are cultivated first, while flat interfluves remain forested or swampy.

In northern region 3 of mixed farming - cultivation and stock raising, also with highly selective land-use due to a high spatial variability of the landscape, the distribution of arable land and pasture is complicated, but the rate of erosion on the arable land is rather constant due to similarity of terrain, selected for farming. In regions 4 and 5 of intensive and maximum extent of agriculture, arable land comprises up to 60-70% of the area, and the erosion rate is both high and variable. In region 6 the pasture area increases and mixed farming (cultivation and stock raising) prevail again. In region 7 sheep grazing is the main type of agriculture.

Local events of intensive runoff cause close to catastrophic erosion rates. Khokh and Zhilko (1981) reported an erosion rate of 46 t ha^{-1} on sod-podzols in Byelorus during the snow-melt spring period in 1972. Medvedev and Shabaev (1991) measured an erosion rate of 53.5 t ha^{-1} during spring 1974 on the Privolzhskaya upland, when rainfall combined with melt-water runoff. The same situation on the Azov Sea coastal plain caused an erosion rate of 25 t ha^{-1} for one event (Poluektov, 1984). Catastrophic summer rainfall (72 mm on May 23, 1967) caused an erosion rate of 220 t ha^{-1} from a potato field and 84 t ha^{-1} from a rye field in Byelorus (Zhilko, 1976). On August 20-21, 1976 192 mm of rainfall caused the formation of ephemeral gullies 200 m long, 2 m wide and 0.2-0.3 m deep and a soil loss about 50-100 t ha^{-1} in the area of 2000 ha in the Kursk district (Gerasimenko and Rozhkov, 1976). About 55 mm of rainfall in the Tula district during two hours on August 10, 1997 brought about soil loss of 22-59 t ha^{-1} (Golosov *et al.*, 1999). Such runoff and rainfall events with 10-20 year return period produce 70-80% of the total long-term sheet and rill erosion.

The long-term erosion from large territories was calculated. The Universal Soil Loss Equation (Wischmeier and Smith, 1978) was used to calculate soil loss from rainfall. Soil loss during snow melt was calculated using the model of the Russian State Hydrological Institute (Anon., 1979). The models were modified for European Russia conditions (Larionov, 1993), verified with measurements and showed good results (Litvin *et al*., 2003). A schematic map (Figure 1a, Table 1, column 6) shows the average calculated severity of sheet and rill erosion, specified for administrative districts. On the Baltic Seaboard the average soil loss from the arable land on major uplands is 5-7 t ha^{-1} yr^{-1} (in the south – 8-9 t ha^{-1} yr^{-1}), and on the lowlands – 1.0-1.5 t ha^{-1} yr^{-1}. On glacial landforms in the uplands it reaches 10-12 t ha^{-1} yr^{-1} and on glacial-lake and fluvioglacial plains ~ 2 t ha^{-1} yr^{-1}. Similar relationships are found between soil loss from uplands and plains in central European Russia: Middle Russian Uplands– 7-8 t ha^{-1} yr^{-1}; Dnieper Valley– 12-14 t ha^{-1} yr^{-1} and the Oka-Don and Dnieper lowlands – 0.5-2.0 t ha^{-1} yr^{-1}. By contrast, the lowest erosion rate, in the middle of the Pripyat' wooded lowland in Byelorus, is < 0.5 t ha^{-1} yr^{-1}. The southern Stavropol' upland stands out as having the highest soil loss: 15-20 t ha^{-1} yr^{-1}. The lowlands are characterised by low rates of soil loss: the Caspian Plain loses < 0.5 t ha^{-1} yr^{-1} (this area is hardly subject to erosion at all) and the central Black Sea Plain – 2 t ha^{-1} yr^{-1}.

Table 1. The main characteristics of erosion in European Russia and Byelorus: 1. Country; 2. District index; 3. District name; 4. District area (10^3 ha); 5. Maximum proportion of arable land (%) / the year when this maximum occurred; 6. Mean annual rate of sheet and rill erosion on arable land in the 1970-80s, t ha^{-1} (calculated); 7. Amount of sheet and rill erosion during the period of intensive agriculture (10^6 t) (calculated); 8. Volume of gullies > 70 m long (10^6 m^3); 9. Area, affected by wind erosion (10^3 ha). Here “0” means small (<1000 ha) wind erosion extend.

1	2	3	4	5	6	7	8	9
Russian Federation	1	Leningradskaya	8531	16.3/1868	2.6	683.6	1.03	0
	2	Novgorodskaya	5447	12.4/1868	4.5	734.8	1.47	0
	3	Pskovskaya	5540	32.3/1868	5.8	1822.5	1.46	0
	4	Kareliya	18052	2.5/1887	2.6	167.2	0.00	0
	5	Komi	43371	1.2/1887	6.9	499.3	1.27	~10
	6	Arkhangelskaya	57127	0.6/1950	4.9	166.1	2.83	~10
	7	Vologodskaya	14451	6.2/1950	6.1	802.0	1.02	0
	8	Murmanskaya	14493	0.1/1796	2.6	7.6	1.58	0
	9	Bryanskaya	3485	57.5/1887	4.1	1077.4	14.84	1.2
	10	Vladimirskaya	2912	43.8/1868	5.5	1134.7	10.92	0
	11	Ivanovskaya	2342	43.8/1868	6.5	1218.9	3.59	0
	12	Tverskaya	6020	31.7/1868	5.3	1554.9	2.56	0
	13	Kaluzhskaya	2978	53.7/1868	7.4	1589.2	12.79	0
	14	Kostromskaya	6020	20.6/1868	5.6	1128.4	7.29	0
	15	Moskovskaya	4689	39.0/1861	7.7	2413.7	8.85	0
	16	Orlovskaya	2465	68.2/1980	5.3	1349.8	35.90	0
	17	Ryazanskaya	3961	56.0/1868	3.5	1344.1	11.56	20.5
	18	Smolenskaya	4978	38.1/1868	7.7	2120.5	13.04	0
	19	Tul’skaya	2568	74.0/1887	7.5	2324.8	15.19	0
	20	Yaroslavskaya	3620	35.1/1868	5.4	1206.3	3.81	0
	21	Mari-El	2237	49.6/1887	7.1	1678.6	12.56	0
	22	Mordoviya	2613	62.4/1887	6.0	1928.1	41.22	0
	23	Chuvashiya	1835	49.6/1887	8.6	1808.4	24.14	0
	24	Nizhegorodskaya	7462	42.5/1887	6.7	3913.8	13.28	0
	25	Vyatskaya	12035	34.1/1887	6.2	4092.3	12.04	0
	26	Belgorodskaya	2713	72.0/1887	7.8	2433.0	43.09	0
	27	Voronezhskaya	5222	69.7/1887	3.6	1907.4	33.11	163.8
	28	Kurskaya	3000	72.8/1887	6.0	1991.2	19.47	0
	29	Lipetskaya	2405	70.0/1950	9.2	914.8	46.82	0
	30	Tambovskaya	3446	66.5/1980	1.7	685.5	14.39	34.4
	31	Kalmykiya	6855	13.9/1980	2.3	196.5	6.01	2103.2
	32	Tatarstan	6784	55.4/1980	2.9	3227.1	28.05	0
	33	Astrakhanskaya	5303	8.0/1980	0.3	10.1	1.58	1692.8
	34	Volgogradskaya	11294	51.7/1980	1.7	822.5	32.67	234.8
	35	Samarskaya	5360	57.8/1980	2.3	950.9	25.22	60.2

	36	Penzenskaya	4335	62.4/1887	4.3	2661.3	32.90	0
	37	Saratovskaya	10124	63.1/1980	1.9	1473.7	28.56	124.6
	38	Ul’yanovskaya	3718	53.3/1887	4.4	931.9	3.52	10.6
	39	Krasnodarskiy	8328	58.4/1950	5.4	1780.9	8.71	1023.0
	40	Stavropol’skiy	7279	66.1/1950	10.0	3346.3	14.69	617.8
	41	Rostovskaya	10097	60.8/1980	3.1	1767.7	18.21	2227.0
	42	Bashkiriya	14294	35.3/1980	3.0	1621.2	1.38	143.0
	43	Udmurtiya	4206	36.7/1980	9.7	1829.6	25.08	30.0
	44	Orenburgskaya	12369	36.5/1980	2.1	1156.8	1.62	384.0
	45	Permskaya	16024	16.4/1980	12.1	3135.2	8.09	0
Byelorus	67	Brestskaya	3278	41.3/1868	1.2	275.7	1.19	0
	68	Vitebskaya	4005	45.2/1868	4.5	1403.1	2.42	0
	69	Gomel’skaya	4036	32.7/1796	0.9	180.2	2.13	0
	70	Grodnenskaya	2511	41.3/1868	4.9	1055.0	3.50	0
	71	Minskaya	4021	32.7/1796	4.5	993.1	1.62	0
	72	Mogilyevskaya	2908	45.7/1868	3.1	687.1	5.54	0

The mean calculated rate of sheet erosion on arable lands is 4.8 t ha^{-1} yr^{-1} in European Russia. On 13.2% of the arable land the rate of erosion is < 0.5 t ha^{-1} yr^{-1}, on 33.6% it is within the range 0.5-2.0 t ha^{-1} yr^{-1}, on 26.8% – 2.0-5.0 t ha^{-1} yr^{-1}, on 13.3% – 5.0-10.0 t ha^{-1} yr^{-1}, on 9.1% – 10.0-20.0 t ha^{-1} yr^{-1}, and on 4.0 % the erosion rate exceeds 20.0 t ha^{-1} yr^{-1}. In Byelorus the mean rate of erosion is lower: 3.6 t ha^{-1} yr^{-1}. The distribution of different levels of erosion on the arable land is 60.5; 3.6; 11.7; 9.8; 11.1 and 3.3%, respectively, with significant bias to low rates of soil loss. Calculated annual soil loss in European Russia in 1970-80s was ~ 420 million tonnes from 88.7 10^6 ha of arable land. In Byelorus the total soil loss was ~ 20 million tonnes from 5.8 10^6 ha of arable land.

2.2. Historical sheet and rill erosion during the period of intensive agriculture

Change in the degree of erosion in European Russia and Byelorus may be calculated using recent rates of slope erosion and estimates of change in the principal factors causing erosion: the area under cultivation, precipitation and land-use. Allowing for the relative change in the values of erosion factors, retrospective calculations were made to estimate the intensity of erosion (Sidorchuk and Golosov, 2003). The volume and the rate of soil loss for the period of intensive agriculture were thus calculated (Figure1b, Table 1, column 7).

According to those estimates for the period from the 18th to the 20th century, erosion was related to the spatial differentiation of erosion factors and the history of the spread of cultivation in European Russia and Byelorus. In the 18th century, erosion

was highest in the most densely populated and cultivated area of the sod-podzols.
Two main areas stand out as having the most intense erosion: in the west, the Smolensk - Moscow region, and in the east, the middle Volga valley. On 94% of arable land (88% in Byelorus) the eroded layer did not exceed 10 cm. In the Smolensk - Moscow region and the middle Volga valley the eroded layer reached 20-30 cm on 8-9% of arable land. The depth of erosion was up to 20 cm on 12% of arable land in Byelorus (25-40% in Brestskaya and Vitebskaya districts). However, for sod-podzol soils, where the humus horizon does not exceed 15-20 cm and the rate of soil formation is no more than 2-3 cm in 100 years (under natural vegetation), such erosion rates are sufficient to produce moderate to severely eroded soil.
In the 19th century the heaviest erosion still occurred in the long-tilled areas of the sod-podzols. Erosion increased after the reform of 1861 as a result of the ploughing of both land previously deemed unsuitable for cultivation and steeper hillsides. Consequently, by 1887 in the Moscow area of heavy erosion, the eroded layer exceeded 10 cm on 40% of arable land, and on 22% of arable land it exceeded 30 cm. In the middle Volga valley, on 63% of arable land, erosion reached >10 cm, and on 14% – > 30 cm. In Byelorus, where the arable land area was more stable and even decreased in several districts, the depth of erosion exceeded 20 cm on only 7% of arable land.
The beginning of land tillage in the Chernozem (black-earth) forest steppe and steppe belt of European Russia led to the formation of the south-western and central black earth zones of intensive erosion. In the south of the Belgorod district the eroded layer was > 10 cm deep on 30% of arable land. However, for the developed chernozems, which typically have a humus layer up to 80-90 cm thick, and a soil formation rate under natural vegetation of 4 - 4.5 cm per 100 years, such erosion rates led to changes in soil structure, which did not exceed the range of natural variation. Therefore, they were not always recorded in soil erosion surveys.
In the 20th century (for our calculations – 1887-1980) the intensity of erosion on long cultivated land on the sod-podzol soils decreased substantially. This was connected to a reduction in the tilled area, mainly because ploughing ceased on the most heavily eroded land and on steep slopes. This accounts for the fact that the total erosion of plough-land increased only slightly. In the Central Chernozem Belt erosion to a depth of > 30 cm covered 7% of arable land in the Belgorod district, and up to 22% in the

Tula district. A southern erosion area developed on newly cultivated land in the Stavropol' district.

Calculations show (Sidorchuk and Golosov, 2003) that in European Russia, during the period 1696-1796, a total of 5.9 10^9 m^3 of soil was washed away by sheet and rill erosion; in 1796-1887– 30.8 10^9 m^3; and in 1887-1980– 33.8 10^9 m^3. The constant increase in the volume of soil loss per unit time (Table 2) is due to an increase in the area under cultivation. Soils in the sod-podzol area are the most affected, particularly in the Middle Russian and Volga uplands, in the north and south-west of the Central Chernozem Belt (Figure 1b). The total volume of calculated soil loss from slopes in European Russia over the period from the 18th to the 20th century inclusive amounts to 70.5 10^9 m^3.

In Byelorus, during the period 1696-1796, 0.74 10^9 m^3 of soil were washed away by sheet and rill erosion; in 1796-1887, 2.02 10^9 m^3; and in 1887-1980– 1.51 10^9 m^3. The maximum volume of soil loss in the 19^{th} century is due to the maximum area of the arable land. Soils in Vitebskaya and Grodnenskaya districts in north-west of the Byelorus were the most affected (Figure 1b). The total volume of calculated soil loss from slopes in Byelorus over the period from the 18th to the 20th century inclusive amounts to 4.3 10^9 m^3.

Table 2. Calculated sheet and rill erosion (10^9 t) during the period of intensive agriculture

Country	Years						
	1950-1980	1887-1950	1868-1887	1861-1868	1796-1861	1763-1796	1696-1763
European Russia	12.65	21.1	16.22	1.68	3.54	3.83	2.11
Byelorus	0.67	0.84	1.52	0.16	0.34	0.46	0.28

This huge amount of eroded soil resulted in substantial reduction in soil depth, mainly in humus and illuvial horizons ($A+B_1$). On the morainic hills of the Valday Experimental Station in the Novgorod district the cover layer of silt deposits with sod-podzol soil is 25-38 cm thick under the forest. This depth was used as the reference depth of non-eroded or slightly eroded soil. Under the arable land the silt deposits were 3-14 cm deep and in 30% of the area they were completely washed away (Lidov, 1976). In the Ul'yanovsk district the depth of $A+B_1$ horizon of non-eroded chernozems is 80-90 cm on flat land and 55-60 cm on gentle slopes. The mean thickness of these horizons for the complicated sporadic pattern of slightly eroded and moderately eroded soils on the slopes between ephemeral gullies is 30-40 cm. This thickness decreases to 10-20 cm in ephemeral gullies with a density ~ 3 km km^{-2} (Lidov et al., 1973). At the Ergeni upland in the Volgograd district the reference thickness of A horizon of non-eroded grey-brown soil is 15-20 cm, and that of B_1 horizon is 31-49 cm on the slopes of the Tinguta dry valley. Here the A horizon is completely washed away on severely eroded soils, and the B_1 horizon is 8-19 cm deep (Lidov and Orlova, 1970). Detailed mapping of soil horizon depth transformation makes it possible to estimate the volumes and rates of erosion for the experimental sites and small catchments with chernozem soils during the period of intensive agriculture (Table 3).

Table 3. Soil loss for the period of intensive agriculture, estimated with the method of soil horizon transformation (after Azhigirov *et al*., 1992)

Basin	Area, (ha)	% of arable land	Soil loss volume, (m^3)	Erosion rate, (mm yr^{-1})	District
Veduga Creek	7034	70	4026	0.67	Voronezhskaya
Malyi Kolyshley River	11775	75	19017	1.26	Saratovskaya
Gor'kaya dry valley	9235	30	1863	0.23	Stavropol'skiy
Large Pogromka River	22420	72	10477	0.52	Orenburgskaya

Intensive agriculture has resulted in the loss of fertility of soils; increased erosion, changes to the microflora and chemical composition of the soils because of changed vegetation, and altered soil water conditions. One of the most important changes has been dehumification, reducing both the soils' agricultural productivity and resistance to erosion. Grinchenko et al. (in Kaurchev, 1989) showed that, during ploughing, the humus content is reduced in chernozems and is distributed more evenly with depth in the humus and illuvial horizons (Table 4). Priputina (1989) compared the humus contents of chernozems of the Russian Plain determined by Dokuchaev at the end of the 19th century with those of the present (maps showing these contents for the two periods have been published by Alayev *et al*. (1990)). Priputina showed that the eastern part of the Plain experienced high losses of humus of 4-10% after 100 years of agriculture. Losses of 1-4% occurred in the western part of the Plain. This pattern is explained by the more intensive erosion processes in the eastern area, leading to further erosion as the erodibility of the dehumified soils increased.

Table 4. Effect of long term agriculture on the humus content of chernozem soils of long-term agriculture (humus content is in %)

Soil horizons	Depth of horizons (cm)	Virgin lands	Ploughed fields			
			12 years	37 years	52 years	100 years
A	0-12	9.4	7.8	7.3	5.9	5.5
A	12-25	6.6	7.5	7.2	5.7	5.3
A	25-35	5.9	6.2	5.8	5.2	5.2
B1	50-60	3.8	4.5	4.5	4.1	4.2
B2	140-150	1.3	1.2	1.4	1.7	1.4

3. Gully Erosion

3.1. Gullies: distribution in the territory

The territory of European Russia and Byelorus was divided (Litvin *et al.,* 2003) into the following four belts according to the genesis and the density of gullies (Figure 2a):

1. The belt of contemporary natural gully thermo-erosion (erosion of the frozen ice-containing soil both by thermal and mechanical action of water). The density of such thermo-gullies (the gullies, where thermal destruction of ice inter-layers in soil is of the same importance, as mechanical erosion) can locally reach >100 gullies/100 km^2. Near the towns, quarries, gas and oil fields, the natural instability of the landscape with the permafrost is increased by human impact, and the rates of initial gully growth can become catastrophic – up to several hundred m per year.

2. The belt where gullies represent extremely uncommon and isolated phenomena (<2 gullies/100 km^2) on non-tilled or little tilled land with flat or rolling relief in the northern (> 57-58° N) part of the forest zone or low-lying land with valleys < 10 m deep (like Poles'ye).

3. The belt of low gully density varying between 2 and 25 gullies/100 km^2 over most of the area. Such areas have low relief with forested flat interfluves. They occupy the forest zone south of 57-58° N, part of the Dnieper lowland plain, the wooded upland flat areas of the Smolensk and Middle Russian uplands, and part of the Oka-Don plain. In the southern part of the forest zone the density of gullies can reach 25-50 /100 km^2. Gullies in the forest were formed during the periods of much broader extension of tillage of the former arable lands.

4. The principal belt of gullying in the forest steppe and steppe zones. The main human factor in gully formation here is tillage of almost the entire area. Gullying is also fostered by natural conditions: substantial volumes of melt water and rainfall, relatively erodible loess subsoils and greater relative relief. When these areas were first cultivated, intensive tillage led to the formation of a gully system of the greatest extent and density, compared to other regions. Relative relief and land-use differentiate the gully density within the belt. Areas with moderate gully density, 25-50/100 km^2 are typically in relatively flat ranges and uplands with shallow relief dissection (the Smolensk Hills, the north-western part of the Middle Russian Upland), as well as in rolling plains (the Tambov district, the Oka-on plain, the western part of the Obshchiy Syrt). Areas of advanced development

with relatively favourable natural conditions for gully formation are characterised by deeply dissected relief and high gully density: 50-100/100 km^2. Such regions include the central parts of the upland country: the Central Russian region and the Volga upland. Areas with very high gully density (> 100/100 km^2) are found in a relatively small region in the middle of the upland country and along riverbanks, comprising <10% of the entire gullied land.

5. The southern belt with very low gully density. This region includes the greater part of the Azov and Black Sea coastlands and the Caspian lowland.

The mean gully density in European Russia (3.8 million km^2) is 28 gullies/100 km^2. The gully net (Moryakova et al., 1987) is formed by 1,045,600 gullies with the total length 114,540 km, an area of 1040 km^2 and a volume of 3.5 billion m^3. In Byelorus (0.2 million km^2) gully density is 7 gullies/100 km^2, the net is formed by 14,500 gullies, which total 1700 km long, with an area 16 km^2 and a volume of 0.054 km^3. These gullies have a length of > 70 m and were formed mainly during the period of intensive agriculture (the last 300-400 years).

Kosov (1970) collected more than 300 measurements of gully growth rates in European part of the former USSR for various land-use types (Table 5). About 45% of these data show gully growth during 1-5 years, 35% - up to 10 years, the others for longer periods up to 170 years. The gullies on arable land are characterised mainly by medium rate of growth (50% of the gullies have a maximum growth rate < 5 m per year). Catastrophic (>100 m yr^{-1}) rates of gully development are more typical for the areas of forest logging and industrial development.

Table 5. Distribution (in %) of gullies with different growth rates (after Kosov, 1970)

Land-use type	The total number of gullies	Maximum annual (seasonal) growth (m)				
		<5	6-15	20-40	50-80	>100
Agriculture	269	50	25	15	8	2
Logging	15	25	18	25	7	25
Road building	17	15	25	30	25	5
Industrial development	19	20	20	25	10	25

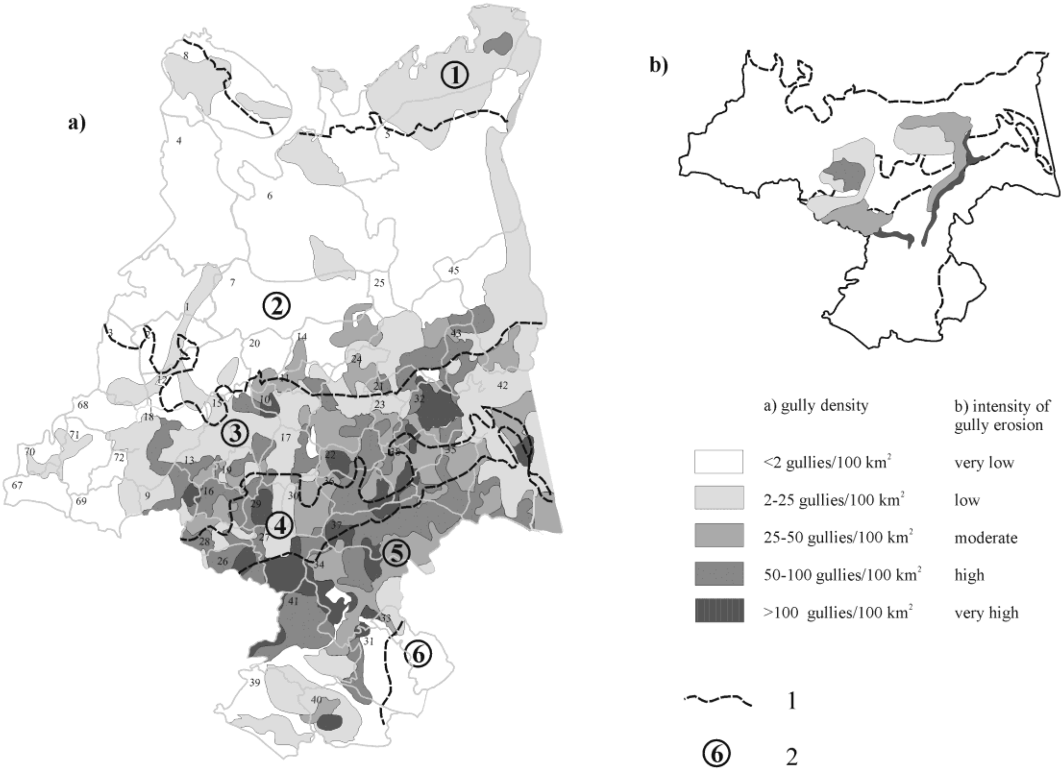

Fig. 2. (a) Distribution of gullies on the Russian Plain, showing contemporary density (number of gullies per 100 km^2) and (b) categories of gully erosion intensity in the1930-40s (after Kozmenko (1954)). Key: 1 - boundaries between vegetation zones; 2 – vegetation zone index: (1) – tundra; (2) – taiga; (3) – mixed and broad-leaved forest; (4) – forest-steppe; (5) – steppe; (6) – semi-desert.

3.2 Changes in the Rate of Gully Erosion

In the development of gully erosion the same stages can be seen as in slope erosion. Using data from the chronicles of the 12 - 14th centuries and land registries for the 15 - 17th centuries, Sobolev (1948) noted severe linear erosion in towns and villages of the forest zone. Moryakova (1988) has dated > 500 gullies in the sod-podzol soil region with the help of organic carbon content in the initial soils in the gullies. These data show five main periods of intensive gully growth with the maximum rate of gully formation in 1860-1910, when ~ 24% of now existing gullies were formed (Table 6).

Table 6. The main stages of gully formation in the sod-podzol soil belt (after Moryakova (1988) with additions).

Period	% of the gullies formed during	Volume of the gullies in 1970 (10^6	The rate of gully formation (%/a)

	the period	m^3)	
1970-1910	9.0	16.5	0.15
1910-1860	24.2	44.4	0.48
1860-1730	40.4	74.2	0.31
1730-1600	21.2	38.9	0.16
1600-1500	5.2	9.5	0.05

The period of the fastest development of gullies within the forest-steppe zone of European Russia was the second half of the 19th century. Massal'sky (1897) used responses to his special questionnaire from correspondents throughout European Russia to obtain the first overview of the extent of gully erosion in the Chernozem Belt of European Russia. The highest intensity of gullying coincides with the areas of historically early cultivation within the Chernozem zone (the Tula and the Kursk districts). Two other periods with the growth of new gullies were registered in the forest-steppe and steppe zones during the late 19th and the middle 20th centuries. They were connected with cultivation of virgin lands, beginning from the end of 19th century and up to the 1950s, and in some areas also with the restarting of cultivation after World War II. An attempt to compile a map of the gully regions (Figure 2b) was undertaken by Kozmenko (1954) for areas of the Middle Russian uplands and the Volga valley with the most sharply dissected relief. The data on gullying relate to the 1930 - 40s.

The tendency towards decreasing gully erosion rates during the second half of the 20th century is noted for all European Russia. According to field observations (Butakov et al., 2000), it reduced 2-3-fold compared to the data for the beginning and middle part of the century, collected by Kosov (Table 5) The most recent observations by Rysin (1998) in the Udmurtiya show mean gully annual growth within the range 2.1-2.2 m during the last 40 years. The maximum measured rate for a 15-year period was 40 m per year.

4. Sedimentation of Small Rivers

4.1. Spatial distribution of sedimentation types

Field studies and map analysis makes it possible to pinpoint typical forms of sedimentation in small rivers (Litvin *et al*., 2003). Their spatial distribution allows the classification of European Russia and Byelorus on the basis of combinations of natural and man-induced conditions. The following areas can be distinguished (Figure 3a):

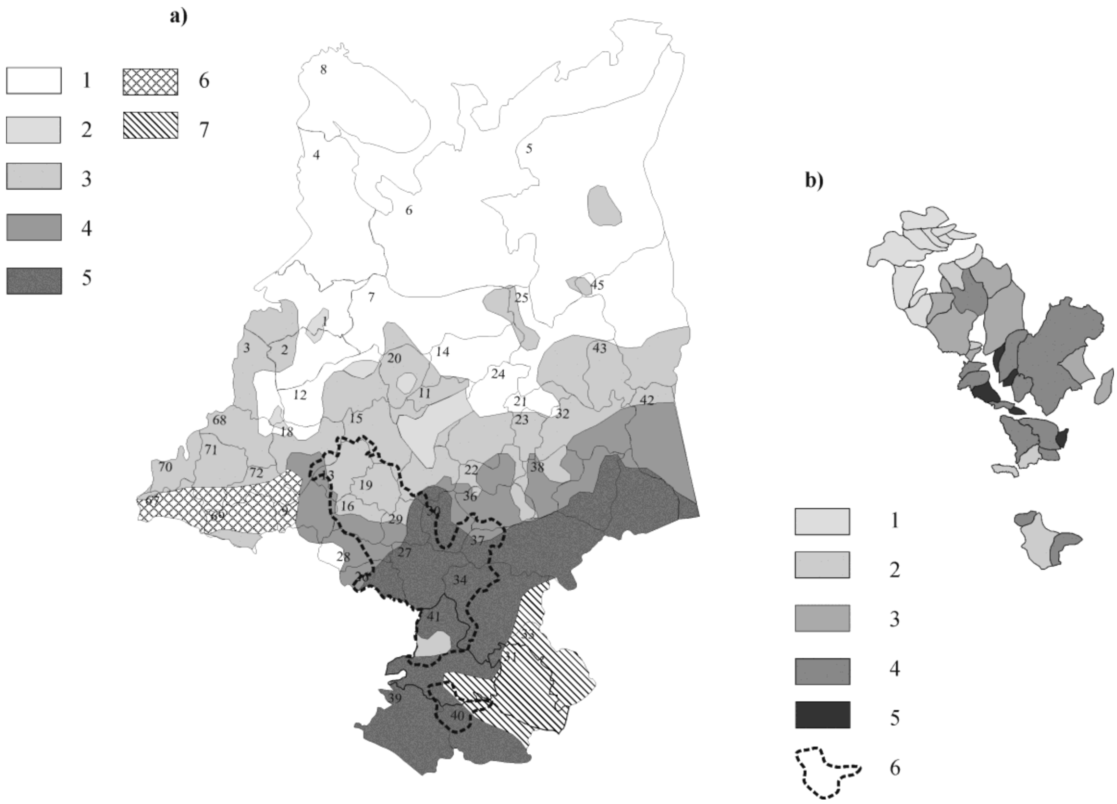

Fig. 3. (a) Distribution of typical forms of sedimentation in small rivers in European Russia and Byelorus and (b) length of river net in a number of river basins in the middle of the XX century in % to that of the beginning of the XIX century. Key: (a) – see the text; (b) 1 - 90-110%; 2 - 75-90%; 3 - 60-75%; 4 - 45-60%; 5 - 25-45%; 6 – outline of Fig. 3b on Fig. 3a.

1. Areas with predominant meandering rivers preserved in their natural, non-sedimented state with firm well defined banks and a dry flood plain. This area is thinly populated and little cultivated, being in the forest zone. Mean channel gradients of 0.2-0.8 $^{o}/_{oo}$ ensure the transport of suspended sediments to the river mouth.

2. Areas in which rivers with swampy floodplains predominate: the rivers flow in wide relict valleys with very low gradients (0.05-0.15 $^{o}/_{oo}$). The configuration of channels in swamps is highly erratic. Their width and depth change within very broad ranges (15 - 20-fold), and sometimes a channel disappears and water seeps across the swamp. Natural swampland is very vulnerable to man-induced sedimentation.

3. Areas with both sedimented and non-sedimented rivers. Here incipient sedimentation in the channels of creeks adjoining major cropland and farming areas occurs, while creeks and rivers of the same size flowing through forests and flood plains remain in their natural state.

4. Areas in which creeks are mostly sedimented, while small rivers remain in their natural state. These conditions occur in the south of the forest zone and in the forest-steppe zone, where arable land occupies < 70% of total catchment area. Most sediment from the slopes reach creeks up to 20 km long, where large-scale sedimentation occurs. This reduces deposition in the watercourses of the small rivers. Thus the creeks and flood plains serve as a buffer between the slopes and the rivers.

5. Areas with sedimentation of all small rivers and some of the medium-sized ones. In the steppe zone, under conditions of intensive tillage of catchments, heavy water use, the regular droughts and sharp flow peaks, the sediment yield from slopes can reach small and medium rivers. The result is that an ordinary channel spreads into a swampy network, in which the old channel is overgrown with reeds and marked only by firm dry banks.

6. Areas with sedimentation of swampy floodplain-type rivers.

7. Areas of local internal drainage with very low drainage density, as well as riverless areas.

These areas broadly correspond to the natural landscape zones. Areas with no sedimentation coincide with tundra and taiga with their high runoff coefficient; those with both sedimented and non-sedimented rivers tend to be related to the mixed and deciduous forest zone; those with sedimentation in the upper reaches of the rivers often correspond to the forest steppe; heavily sedimented rivers are found in the steppe zone with low runoff coefficients; and inland drainage areas coincide with the arid steppe and semi-desert zones. At the same time, however, the outlines of these areas are more complicated than those of the landscape zones, and their limits frequently do not coincide with those of the latter ones. This may be because the type and level of the economic activity does not correspond to the geographical or terrain zones (as, for example, the penetration of agriculture into the taiga), and because of the azonal geological and geomorphologic factors. The latter determine shapes of the longitudinal profiles of rivers, the values of local slope gradients, and the erosion and sedimentation capacity of watercourses. Areas, shaped mainly by neotectonics and geomorphology with swampy floodplain-type rivers, are scattered sporadically over all regions.

4.2 Stages of Aggradation in the River System

Permanent watercourses are quite sensitive to changes in climate and land-use. The hydrological and sedimentological regimes of small rivers in European Russia and

Byelorus are controlled by changes in the forest cover and proportion of arable land in their catchments. Contemporary data (Golosov and Panin, 1998) show that tillage of up to 30% of the catchment area affects only the water runoff and sediment yield, without reducing the length of the river system due to sedimentation. Data from 130 sites on 75 rivers with basin areas < 100 km^2 located in the middle part of the Volga river basin demonstrate that the deposition rate on the floodplain depends on the area of arable land in the catchment. The total thickness of sedimentation during the agricultural period is ~ 1 m for basins < 20% forested, and close to zero in the completely forested basins (Kurbanova and Petrenko, 1990). Acceleration of floodplain aggradation is marked even for large rivers. Archaeological data show that aggradation rates for the period 2500-200 years ago were ~ 0.6 mm/a in the Middle Oka River floodplain and they increased to 6-6.5 mm yr^{-1} in the last 200 years (Glasko and Folomeev, 1981). Massal'sky (1897) noted that the Svirnya River (Don River tributary) was prone to sedimentation and some late 18th century coins were found in sediments at 1 m depth. The thickness of sedimentation was estimated at the bottom of 11 small valleys with basin areas of 5-40 km^2 in different regions of European Russia (the Middle Oka, the Upper and Lower Don, the Lower Volga, the Ural River and Stavropol' Region). It ranges from 1.0 to 2.8 m, with the mean aggradation rates of 3 - 38 mm yr^{-1} for the period of intensive agriculture (50-350 years) (Golosov et al., 1991).

The spatial distribution of aggradation in small rivers was estimated on the basis of measurements of the length of the permanent stream net. The comparison of the 1:420,000 scale map of 1826-1842 and the 1:300,000 map of late 1940s - early 1950s was made (Golosov & Panin, 1998) from the Upper Oka river basin in the north to the Kalaus river basin in the south (Figure 3b). During this 100-year interval there was no essential change in the length of permanent streams in humid landscapes of the southern part of the forest zone. Some rivers with densely forested catchments slightly increased the extent of the river system, due to the process of incision into water tables in formerly dry valleys. The process of river shortening becomes evident towards the south-east of the forest zone and reaches high values (decrease of the river net length by > 50%) in the semi-arid regions (the southern forest steppe and the northern steppe). Relief, ground water, soils and rock type affected the spatial distribution of river net reduction. The length of the river net decreased by 42% in the Middle Russian Upland and by 31% in the Oka-Don Lowland (both are located in the forest steppe zone). In the Medveditsa River basin, where the right-hand tributaries are fed by significant volumes of groundwater, the reduction of the left bank tributaries was 21% and only 9% for the right bank tributaries. The high rates of sedimentation in the rivers of the Khoper basin can be explained by the high soil erodibility (sand and silt).

The volume of sedimentation in rivers of different sizes may be estimated using data on catchment erosion and sediment delivery ratio. These estimates show (Sidorchuk, 1995) that in the last 300 years most sedimentation has been concentrated in the floodplains and channels of dry valleys and creeks 10 - 25 km long. The volume of sediment diminishes from west to east, as well as to the north and south of the central zone of maximum sedimentation. This zone embraces the Oka basin (deposition thickness h = 2.7-3.1 m) and the Vyatka and upper Kama basins (h = 1.9 - 2.7 m). North-west of this zone the depth of sediment declines to 1.1- 2.4 m (upper Don and Volga basins) and to the south-west to 0.5-2.3 m (the Don and middle and lower Volga basins). The measurements in the deltas of the major rivers show that only 6-7% of eroded soil is transported to the seas, and the main part sequestered in the fluvial system (Sidorchuk, 1995).

5. Other soil loss processes

5.1. Wind erosion

Wind erosion prevails on arable land in the south-eastern part of European Russia (see Figure 1), where silt soils on the hilltops and leeward slopes are easily dried and deflated by winds (Larionov, 1993). The frequency and intensity of wind erosion events increased with the expansion of agriculture in this region: nine “black” storms were observed in the 19th century, five during the first 30 years of the 20th century and 25 observed in 1940-70^{s}. Between 3 and 30 less intensive “dust” storms with the wind velocities up to 10-30 m s^{-1} occur each year. The most catastrophic were the “black” storms of 1969-70, which happened when some fields, not protected by the forest buffer strips, lost 0.26 cm of soil on average (and up to 70 cm in some places). Many forest buffer strips were completely buried with soil and formed elongated hills 2-3 m high and 30-50 m wide and these remain in the landscape. The soil dust from these storms was observed in the Ukraine and Moldavia, Sweden and The Netherlands (Larionov et al., 1996). Annual soil loss due to wind erosion is estimated as 5-40 t ha^{-1} in the Northern Caucasus and 5-22 t ha^{-1} in the Lower Volga region (Larionov, 1993).

Wind erosion on pasture is associated with light sandy soils and overgrazing. It is common in the tundra zone, where reindeer overgrazing leads to formation of active sand dunes around towns and villages. The same type of movable sand destroys pastures in the Kalmykiya and in the Lower Don region, due to sheep overgrazing.

5.2. Tillage erosion

The influence of tillage (mechanical) erosion on the fields of European Russia and Byelorus is evident. Most of the convex interfluvial areas on the fields show truncated soil profiles, often with B or C horizon exposed on the field surface. Narrow bands of accumulated soil 10-20 cm high mark the field edges. This process is more obvious on sod-podzol soils (Zaslavskiy, 1983). Tillage erosion is combined with intensive water erosion on convex-concave slopes. On such slopes stable systems of ephemeral gullies are formed during the melt period or summer rainfall. When ploughs and harrows level the field, the trenches of ephemeral gullies are filled by loose topsoil from surrounding areas, and thus soil profiles become thinner. Melt water flow or intensive rainfall renews the incision of the ephemeral gullies and removes most of their infill from the field. The cycles of levelling by tillage and dissecting by erosion lead to general intensive soil loss. Observations on the soil profile truncation on one of such field (170 ha) in the Stavropol' district showed the decrease of reference chernozem soil depth ($A+B_1$ = 80-90 cm) during the last 70 years to 36-57 cm on the inter-gully areas and 10-15 cm in ephemeral gullies. The mean annual soil loss from combined tillage and water erosion amounted to 58 t ha^{-1} at this site (Beyaev *et al*., in press).

5.3. Soil loss with the harvest

One of the specific types of soil loss is mechanical removal of soil from fields with the harvest, mainly with potato and root crops (sugar beet, carrot and radish). Zaslavskiy (1983) estimated this loss as 5-10% of the harvest weight. Belotserkovskiy and Larionov (1988) showed by direct measurement of adhered soil from potato and beet in the Kaluzhskaya district that the soil loss with harvest in 1975-80 was 2.5 t ha^{-1} with potato and 2.3 with beet. The measured soil delivery by melt water flow from different fields of the same farm was 0.08-2.0 t ha^{-1} per spring season 1982-89. The reports of one of the crop warehouses in Moscow, where root crops were washed before being delivered to the market, showed a lower proportion of soil in the harvest than the above measurements made near the field (see Table 7). This difference is related with the distance from the field to Moscow and partial loss of adhered soil during transportation. Nevertheless, even this underestimation of soil loss with potato harvest (~0.6 t ha^{-1}) gives ~1.5 million t of annual soil loss from 3 million ha of potato fields in European Russia and Byelorus.

Table 7. Soil delivered to Moscow with potatoes in 1985 (after Belotserkovskiy and Larionov, 1988, simplified)

District	Potato+soil (t)	Soil (t)	Mean harvest in 1981-85 (t ha^{-1})	Mean soil-loss with the harvest (t ha^{-1})
Russia				
Bryanskaya	247.2	3.9	11.6	0.2
Orlovskaya	62.1	1.2	9.1	0.2
Ryazanskaya	1096.7	17.7	9.0	0.1
Moskovskaya	5085.1	346.6	12.7	0.9
Tverskaya	430.9	7.4	10.3	0.2
Kaluzhskaya	4451.5	472.9	10.3	1.1
Byelorus				
Brestskaya	2794.3	50.3	17.1	0.3
Grodnenskaya	847.9	5.9	15.6	0.1
Minskaya	6168.2	164.9	15.3	0.4
Vitebskaya	655.9	11.8	13.6	0.2
Gomel'skaya	814.6	14.8	15.6	0.3
Mogilevskaya	820.9	18.6	14.9	0.3

5.4. River bank erosion

River bank erosion is mainly a natural process in European Russia and Byelorus. The total length of the rivers is 711,855 km, and 93% are sinuous or meandering, with 30-40% the banks affected by erosion. The rate of river bank erosion is controlled by discharge and slope. For small and medium rivers of the Volga and Don basins it increases with the river size (Table 8). On the large rivers, with mean maximum discharge (MMD) > 4000 $m^3 s^{-1}$, the annual rate of bank erosion can exceed 6-10 m (Chalov, 1994): for the lower Vychegda River it is 12-40 m yr^{-1}, for the lower Don it is >6 m yr^{-1} and for the lower Volga it is >10 m yr^{-1}. Eroded particles are mostly deposited within a river channel on the bars and lower floodplain, so that the river channel width remains stable in the long run. For example, on the lower Terek River the mean rate of bank erosion in 1932-72 was 2.7 m yr^{-1}, with local extremes of 10-15 m yr^{-1}. Such a rate corresponds to sediment production of 0.8 10^6 t yr^{-1}. Sedimentation within the active belt of the river was also ~ 0.8 10^6 t yr^{-1}, so that the budget of channel-forming particles was close to zero (Alekseevskiy and Sidorchuk, 1990).

Table 8. Distribution (in % of the river length) of the rate of river bank erosion (after Kamalova, 1988)

	River bank erosion rate m yr^{-1}				
MMD m^3/s	<0.5	0.5-1.0	1.0-2.0	2.0-3.0	3.0-4.0
<300	13	28	53	5	1
300-1000	3	17	39	38	3
>1000	9	19	16	12	44

5.5. Reservoir bank erosion

Bank erosion in artificial reservoirs is a purely human induced process. Here steep profiles of the shore zone, wave height and regime after the reservoir filled with water are completely different from those on natural coasts close to equilibrium. The rate of abrasion is catastrophic and locally exceeds 200 m yr^{-1} in the initial period of reservoir formation, decreasing through time with the increase in the abrasion bench width. The reservoirs in Byelorus situated mainly in the forest zone are rather small: there are 130 reservoirs with a total volume of 2.45 km^3 and an area of 715 km^2. The length of the reservoir banks is 1300 km, and ~ 25% of these are abraded by wave action. A stabilising bench 12-30 m wide and 1.5-2.0 deep appears in 15-20 years in reservoirs with a stable level regime and in 25-30 in reservoirs with variable regime. The loss of land around such reservoirs is ~ 5000 ha (Shirokov, 1991). A similar regime characterises small reservoirs in European Russia.

Soil loss processes at a different scale are observed in the giant reservoirs on the largest lowland rivers of European Russia: Volga, Kama and Don Rivers. The total volume of 16 reservoirs of the Volga-Kama system is 197.3 km^3, with a combined area 2.8 million ha. Arable land constituted 11% of this now-flooded area, 38.8% was pasture and 36.8% – forest (Vendrov, 1979). From 10 to 40% of the shoreline of these reservoirs is intensely attacked by waves. The rates of bank erosion were 10-50 and up to 120 m yr^{-1} during the first 16 years of the life of Rybinskoye reservoir, 25-40 and up to 50 m yr^{-1} for the first 13 years at the Gor'kovskoye reservoir, and 70-90 m yr^{-1} and up to 210 m yr^{-1} for the first 10 years of the Volgogradskoye reservoir (Finarov, 1986).

6. Concluding remarks: land-use trends of the last decades

The most recent information about erosion processes in European Russia and Byelorus belongs mainly to middle 1980s. After that the radical changes in the political situation and economy began in the USSR. The data collected by scientific institutions and government authorities during the last 10-15 years are fragmentary and uncertain. Federal and regional land-use and soil conservation policy is unclear and changeable. Federal statistics of the Russian Federation (Russia in Numbers, 2002) shows dramatic land-use changes. In 25,800 large collective farms and state agricultural complexes, which used 86-93% of the land, the area of arable land decreased by 15%, the area of sowing decreased by 32.5% and the volume of agricultural production decreased by 60% during the years 1990-2000. Changes in the type of management (87% of the former collective farms and state farms became stock companies and co-operatives in 1994) and decreases in food imports in 1998 caused a slight increase in the volume of production during the last years. A considerable amount (30-60%) of food (mainly vegetables) was produced both by the urban and country population (16-19 million families) on private lots (with area ~0.06-0.1 ha each), which on the whole occupy 3-5% of arable land. Individual farmers, who used about 9% of the arable land in the year 2000, produced only 3% of total agricultural production. The number of such farms, with a mean area of 43 ha, sharply increased in the first years of economic changes (from 100 in 1990 to 183,000 in 1993 and 280,000 in 1996), then slightly decreased and has stabilised at the level of 260,000-265,000 farms.

This statistic shows that the main land-user (at least 86% of the land) is still large farms (4000 ha on average) with collective type of land-use. The pattern of the fields (their length and inclination) did not change significantly. About 25% of the fields are not used and covered at present by weeds and scrub. Water erosion is negligible there. The market dictates the crop rotation on the other part of land, and the land conservation methods of management are out of use. Often a mono-crop culture (like sunflower) can be cropped for several years of high prices for this type of production. Water erosion rates on such fields could be significantly higher than in previous years.

The erosion pattern on land used by individual farmers is unclear. Most of these fields, cut out of the large collective farms, are situated on the poorest and eroded soils, and on the slopes. Many of these farms are now abandoned and not used for agriculture. Some of them are exploited without any care about erosion processes and represent potential spots of significant soil loss.

The plots of citizens’ private land are mainly used as vegetable gardens with an organic type of farming. Erosion on arable land of this kind is absent, and soil fertility increases rapidly.

We can conclude that the current situation with erosion processes in European Russia and Byelorus is uncertain. The system of land ownership and management is changing slowly. One of the main effects of this process is a substantial decrease in the land under the plough and, therefore, a decrease of the extent of erosion processes (by 25% at least). Simultaneously, new spots of locally high erosion rates could appear due to the increase in the proportion of farms with specialised unvarying crop rotation. People with no experience of land husbandry are taking up farming. Previous state departments for soil conservation do not work, and the new ones are not yet properly organised. If a repetition is to be prevented of the general degradation of soils that occurred in the late 19th century, following the abolition of serfdom, it is essential that a well-considered state policy of conservation education be pursued, and that a body of laws be designed to promote farming techniques which conserve soils and water resources. A first step in this direction is the content of Chapter 2 "Land Conservation" of The Land Code of the Russian Federation of 2001. This chapter declares the duty of landowners and land-users to keep soil fertility and to prevent water and wind erosion. This declaration shows necessity of a special branch of land-use legislation, as the part of a general environmental legislation (Bogolyubov, Minina, 2002)

References.

Alayev EB, Badenkov YP, Karavaeva NA. 1990. The Russian Plain. In *The Earth as Transformed by Human Action,* Turner BL, Clark WC, Kates RW, Richards JF, Mathews JT, Meyer WB (eds). Cambridge University Press with Clark University: Cambridge; 543-560.

Anon. 1979. *Instructions on Calculating Hydrological Characteristics in Planning Measures to Counter Erosion in The European Area of the USSR*. Gidrometeoizdat: Leningrad. (in Russian)

Alekseevskiy NI, Sidorchuk AY. 1990. Morphology and dynamics of the alluvial relief of the lower Terek River. In *Land and Water Resources,* Chalov R (ed). Moscow Univ. Publ. House: Moscow; 87-94. (in Russian).

Azhigirov AA, Golosov VN, Dobrovolskaya NG, Ivanova NN, Litvin LF. 1992. Soil Erosion Influencing Upper Stretches of Fluvial System. In *Ecological problems of Soil Erosion and Fluvial Processes,* Chalov R (ed). Moscow Univ. Publ. House: Moscow; 66-80. (in Russian).

Belotserkovskiy MY, Larionov GA. 1988. Transport of fines with potato and root crop harvest: part of the soil loss. *Vestnik Moskovskogo Universiteta, Seriya 5,Geografiya* 4:49-54. (in Russian).

Belyaev VR, Wallbrink PJ, Golosov VN, Murray AS, Sidorchuk AY. A Comparison of Direct Measurement, USLE and Caesium-137 Based Methods for Evaluating Soil Redistribution from Severe Tillage, Sheet and Ephemeral gully Erosion, Stavropol Region, Southern European Russia. *Geomorphology*, in press.

Bogolyubov SA, Minina EL. 2002.*Comment to the Land Code of the Russian Federation.* NORMA Publ. House: Moscow (in Russian).

Butakov GP, Zorina EF, Nikol'skaya II, Rysin II, Serebrennikova IA, Yusupova VV. 2000. Tendency of gully erosion development in European Russia . In *Erosion and Fluvial Processes, v.3,* Chalov R (ed). Mosk.Univ. Publ. House: Moscow; 52-62. (in Russian).

Chalov RS (ed). 1994. *The channel regimen of the rivers of the Northern Eurasia.* Mosk.Univ. Publ. House: Moscow. (in Russian).

Dokuchaev VV. 1883. *Russian Chernozem*. Sankt-Peterburg. (in Russian).

Finarov DP. 1986. *Geomorphological analysis and prognosis of reservoir bank and bed transformation*. Nauka: Leningrad. (in Russian)

Gennadiev AN, Gerasimova MI, Patsukevich ZV. 1987. Soil Formation Rate and Admissible Standards of Soil Erosion. *Vestnik Moskovskogo Universiteta, Seriya 5,Geografiya* 3:31-36. (in Russian).

Gerasimenko VA, Rozhkov AG. 1976. Extreme rain storm in Central Chernozem region and Erosion Processes. *Zacshita pochv ot erozii* **4**(11)13-18. (in Russian).

Glasko MP, Folomeev BA. 1981. Determining of Floodplain Aggradation Rates on Lowland Rivers by Archaeological and Geomorphologic Data (Case Study of middle Oka River). *Geomorfologia* 3:26-36. (in Russian).

Golosov VN, Panin AV. 1998. Spatial and Temporal Regularities of River Aggradation Process on Russian Plain. In *Trudy Academii Vodokhoziaistvennykh Nauk, Vol. 5,* Chalov R (ed). AVN: Moscow; 163-171 (in Russian).

Golosov VN, Ivanova NN, Litvin LF, Sidorchuk AY, Chernov AV. 1991. Change in Sedimentation in Small River Catchments in the European USSR. In *The Present State of Small Rivers in the USSR: Their Use, Shrinkage and Restoration*. Snischenko BF (ed). Gidrometeoizdat: Leningrad; 96-103.(in Russian).

Golosov VN, Ivanova NN, Markelov MV. 1999. Extreme erosion during rain-storm in the Chasovenkov Verh balka basin. In *Tezisy dokladov chetyrnadcatogo plenarnogo mezhvuzovskogo sovecshaniya po probleme erosionnyh, ruslovyh i ust'evyh processov*. Bashkirsk university: Ufa; 96-97 (in Russian).

Kamalova EV. 1988. *Geographical principles of the processes of bank erosion on small and median river of Volga and Don valleys. PhD Thesis*. Moscow Univ.: Moscow. (in Russian).

Kaurchev IS. (ed.) 1989. *Soil Science*. Agropromizdat: Moscow (in Russian).

Khokh NY, Zhilko VV. 1981. Peculiarities of erosion processes for podzol soils. In *The main principles of erosion and channel processes in different environment*, Makkaveev N (ed). Mosk.Univ. Publ. House: Moscow; 14-16 (in Russian).

Kosov BF. 1970. Gully growth on the territory of the USSR. In *Soil erosion and fluvial processes, Vol.1*, Makkaveev N (ed). Mosk.Univ. Publ. House: Moscow; 61-78 (in Russian).

Kozmenko AS. 1954. *Principles of anti-erosion land-improvement*. Sel'skhozizdat: Moscow. (in Russian).

Krokhalev FS. 1960. *On Agricultural Systems*. Sel'skhozizdat: Moscow. (in Russian).

Kurbanova SG, Petrenko LV. 1990. Anthropogenic Acceleration of Alluvium Sedimentation in Small Rivers of the East of Russian Plain. In *Exogenic processes and the environment*, Dedkov AP (ed). Nauka: Moscow; 177-181 (in Russian).

Larionov GA. 1993. *Water and wind erosion: the main principles and quantitative estimates*. Mosk.Univ. Publ. House: Moscow. (in Russian).

Larionov GA, Sagin AN, Vasil'yev YI. 1996. Two approaches to wind erosion intensity estimation and its regional analysis. In *Erosion and channel processes. Vol.2.,* Chalov R (ed). Mosk.Univ. Publ. House: Moscow; 78-94(in Russian).

Lidov VP. 1976. Processes of erosion in the area of sod-podzol soils. In *Soil erosion and fluvial processes. Vol.5.,* Makkaveev N (ed). Mosk.Univ. Publ. House: Moscow; 77-112. (in Russian).

Lidov VP, Orlova VK. 1970. Erosion of light chestnut soils in Volgogradskaya district (Ergeni upland). In *Soil erosion and fluvial processes. Vol.1*, Makkaveev N (ed). Mosk.Univ. Publ. House: Moscow; 69-98 (in Russian).

Lidov VP, Orlova VK, Uglova LV. 1973. A significance of rilling in soil cover formation. Makkaveev N (ed). In *Soil erosion and fluvial processes. Vol.1*, Makkaveev N. (ed). Mosk.Univ. Publ. House: Moscow; 35-64. (in Russian).

Litvin LF, Zorina YF, Sidorchuk AY, Chernov AV, Golosov VN. 2003. Erosion and sedimentation on the Russian Plain, part 1: contemporary processes. *Hydrol. Process.* **17**(16):3335-3346.

Medvedev IF, Shabaev AI. 1991. Erosion processes on arable lands of Privolzhskaya upland. *Pochvovedenie* 11:61-69 (in Russian).

Moryakova LA. 1988. Dating of the main periods of gully erosion in the south of sod-podzol soil area of the European USSR. In *Natural hazards 6455-V87,* Myagkov S (ed). VINITI Publ.: Moscow. (in Russian).

Moryakova LA, Nikol'skaya II, Prokhorova SD, Dyachenko IS. 1987. The map of the gully distribution at the European USSR. In *Geography of dangerous natural processes 5524-V88,* Myagkov S (ed). VINITI Publ.: Moscow. (in Russian).

Massal'sky V. 1897. *Gullies in the Russian Chernozem Belt: their distribution, development, and rate of growth*. St. Petersburg. (in Russian).

Russia in Numbers. 2002. Goskomstat: Moscow. (in Russian).

Poluektov EV. 1984. *Soil erosion in Don region and measures of struggle with it*. Rostov University: Rostov-na-Dony. (in Russian).

Priputina IV. 1989. Anthropogenic dehumification of the chernozems of the Russian Plain. *Vestnik Moskovskogo Universiteta, Geography, Ser 5,* 1:59-60 (in Russian).

Rysin II. 1998. About recent trend of gully erosion in Udmurtiya. *Geomorfologiya* 3:92-101 (in Russian).

Shirokov VM (ed). 1991. *Water reservoirs of Byelorus: specific features in the nature and their influence upon the environment*. University Publ.: Minsk. (in Russian).

Sidorchuk A. 1995. Erosion and Accumulation on the Russian Plain and Small River Silting. In *Trudy Academii Vodokhoziaistvennykh Nauk, Vol. 1,* Chalov R (ed). AVN: Moscow; 74-83. (in Russian).

Sidorchuk AY, Golosov VN. 2003. The History of Erosion and Sedimentation on the Russian Plain During the Period of Intensive Agriculture. *Hydrol. Process.* **17**(16):3347-3358

Sobolev SS. 1948. *The Development of Erosion Processes in the European USSR, and the Struggle Against Them, Vol. 1.* Izd. AN SSSR: Moscow and Leningrad. (in Russian).

Tsvetkov MA. 1957. *Change in Forest Cover in European Russia from the Late 17th Century to 1914.* Izd. AN SSSR: Moscow. (in Russian).

Vendrov SL. 1979. *Problems of River System Reorganisation in the USSR.* Gidrometeoisdat: Leningrad. (in Russian).

Wischmeier WH, Smith D.D. 1978. *Predicting Rainfall Erosion Losses.* Agric. Handbook No. 537. U.S. Dept. Agric.: Washington D.C.

Zaslavskiy MN. 1983. *Erosion science*. Vysshaya shkola: Moscow. (in Russian)

Zhilko VV. 1976. Eroded Soils of Belorussia and Their Use. Uradzhai: Minsk. (in Russian).