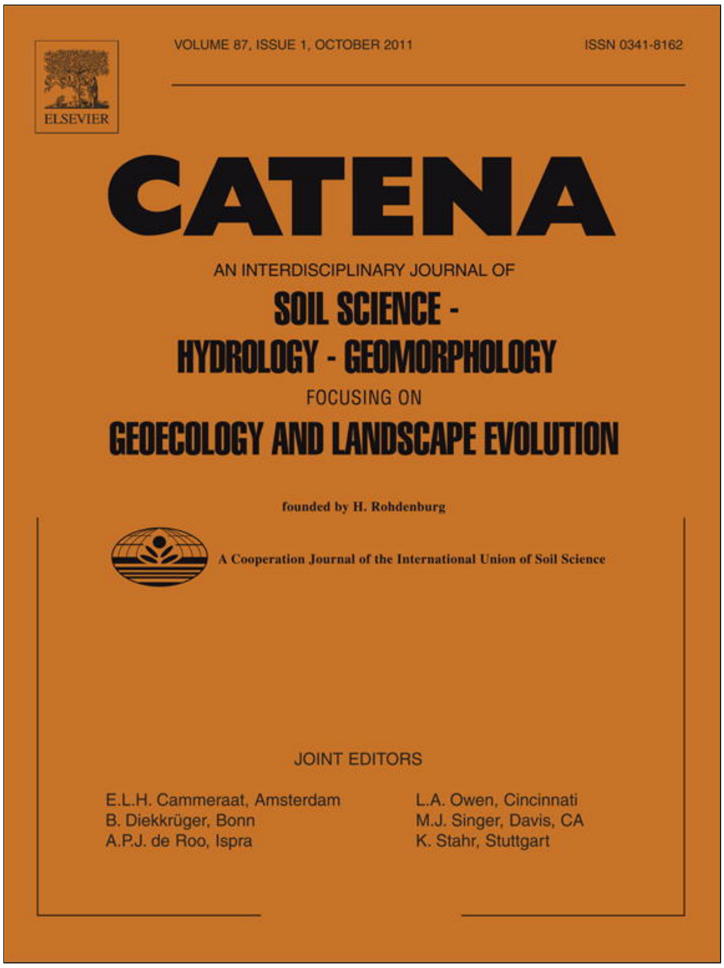

VOLUME 87, ISSUE 1, OCTOBER 2011 ISSN 0341-8162

CATENA

AN INTERDISCIPLINARY JOURNAL OF
SOIL SCIENCE -
HYDROLOGY - GEOMORPHOLOGY
FOCUSING ON
GEOECOLOGY AND LANDSCAPE EVOLUTION

founded by H. Rohdenburg

A Cooperation Journal of the International Union of Soil Science

Catena 87 (2011) 45–51

Contents lists available at ScienceDirect

Catena

journal homepage: www.elsevier.com/locate/catena

Effect of snow amount on runoff, soil loss and suspended sediment during periods of snowmelt in southern West Siberia

A.A. Tanasienko, O.P. Yakutina [*], A.S. Chumbaev

Institute of Soil Science and Agrochemistry SB RAS, Sovetskaya St., 18, Novosibirsk 630099, Russia

A R T I C L E I N F O

Article history:
Received 26 August 2010
Received in revised form 4 May 2011
Accepted 5 May 2011

Keywords:
Snow amount
Surface runoff
Suspended sediment
Soil loss
Texture
West Siberia

A B S T R A C T

Surface runoff, soil loss, suspended sediment concentration (SSC), texture of eroded soils and suspended sediment were determined on slightly eroded chernozems (mouldboard fall-ploughed) during years with different amounts of snow in three areas of southern West Siberia (Predsalairye, Priobye and Kuznetsk hollow). These areas have different geomorphological and climatic characteristics and soils. Observations were made from 1969 to 2007. The soil loss during very low-snow and low-snow years did not exceed 2 t ha^{-1}. After winters with normal amounts of snow, the runoff led to slight soil loss (2–5 t ha^{-1}). Soil losses in high-snow and very high-snow years varied from slight to severe (4.8–15.8 t ha^{-1}) depending on studied area. The main sediment exported during intensive snowmelt and the 1 mm of runoff transported from 35 to 150 kg ha^{-1} of soil material. The removal of soil particles <0.01 mm (especially clay) prevailed during the initial and final stages of snowmelt. Clay removal by meltwater from the ploughed layer in high-snow and very high-snow years varied from 3300 to 4200 kg ha^{-1} and, in the initial and final stages of snowmelt clay removal, accounted for 1260–1,500 kg ha^{-1}. Among the three studied regions, Predsalairye had decreased soil erosion resistance and was the area with the greatest danger of erosion.

1. Introduction

The intensity of erosion on arable land during periods of snowmelt is dependent on many factors. The processes of freezing and thawing and low temperatures in soil reduce the stability of soil aggregates (Oztas and Fayetorbay, 2003; Kværnø and Øygardena, 2006). Countries in northern Europe experience a winter climate that typically has freeze–thaw cycles (Deelstra et al., 2009). In West Siberia, there are no thawing events in the winter, and the soil remains cold and freezes deeply, with the formation of an ice layer at a soil depth of 20–30 cm that lasts for a long period of time (Tanasienko et al., 2009; Yamazaki et al., 2006) and prevents the filtration of meltwater (Cray et al., 2001; Iwata et al., 2010). The snow water equivalent (SWE), the soil moisture content when the snow cover sets, and the air temperature during the autumn and winter seasons also influence soil erosion. Snow cover with a large SWE in Siberia lasts for a long period of time and melts rapidly, causing considerable soil loss, especially on sloped land. Other potential considerations for an eroded area are the slope topography (e.g., direction, steepness, length, and shape), the size and shape of the watershed area and the properties and tillage of the soil and crops (Nord and Esteves, 2010).

The best lands of southern West Siberia are chernozems (13.3 million ha) that are located in relatively flat territory and are completely occupied by arable land (10.7 million ha) (Khmelev and Tanasienko, 2009). Further ploughing of land is possible only at the expense of the soil situated on slopes. Slopes with gradients exceeding 3° are more exposed to erosion than flat land. Approximately 30% of such lands are situated on northern slopes, while 50% are situated on southern slopes. On average, 10% of all arable land is situated on slopes with a gradient of 6–9°, and approximately 5% is located on slopes with a gradient exceeding 9°. Soils on such slopes are exposed to very strong sheet erosion. Predsalairye, Priobye and Kuznetsk hollow are areas in southern West Siberia with almost 2.5 million ha of arable land (Fig. 1). More than 60% of the soils here are chernozems. Approximately 20% of the arable land of this region has already been eroded to varying degrees (Khmelev and Tanasienko, 2009). In West Siberia, there are practically no winter crops, which shield the soil surface from erosion. Absence of winter crops is connected with crop destroy due to frost (in very low-snow and low-snow years) or oversaturation of the soil with moisture (in high-snow and very high-snow years). With regard to land use in Siberia, spring crops occupy more than 80% of arable land, while grasslands occupy approximately 10%. The main tillage is mouldboard fall-ploughed to a depth of 22–24 cm. Therefore, meltwaters transport a considerable quantity of soil material.

Surface runoff is accompanied by the selective removal of soil particles of different sizes during periods of rainfall (Dangler and El-Swaify, 1976; Lal, 1976, 2005; Steegen et al., 1998) or snowmelt

---

[*] Corresponding author. Tel.: +7(3832)225579.
E-mail addresses: oyakutina@yandex.ru, yakutina@issa.nsc.ru (O.P. Yakutina).

0341-8162/$ – see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.catena.2011.05.004

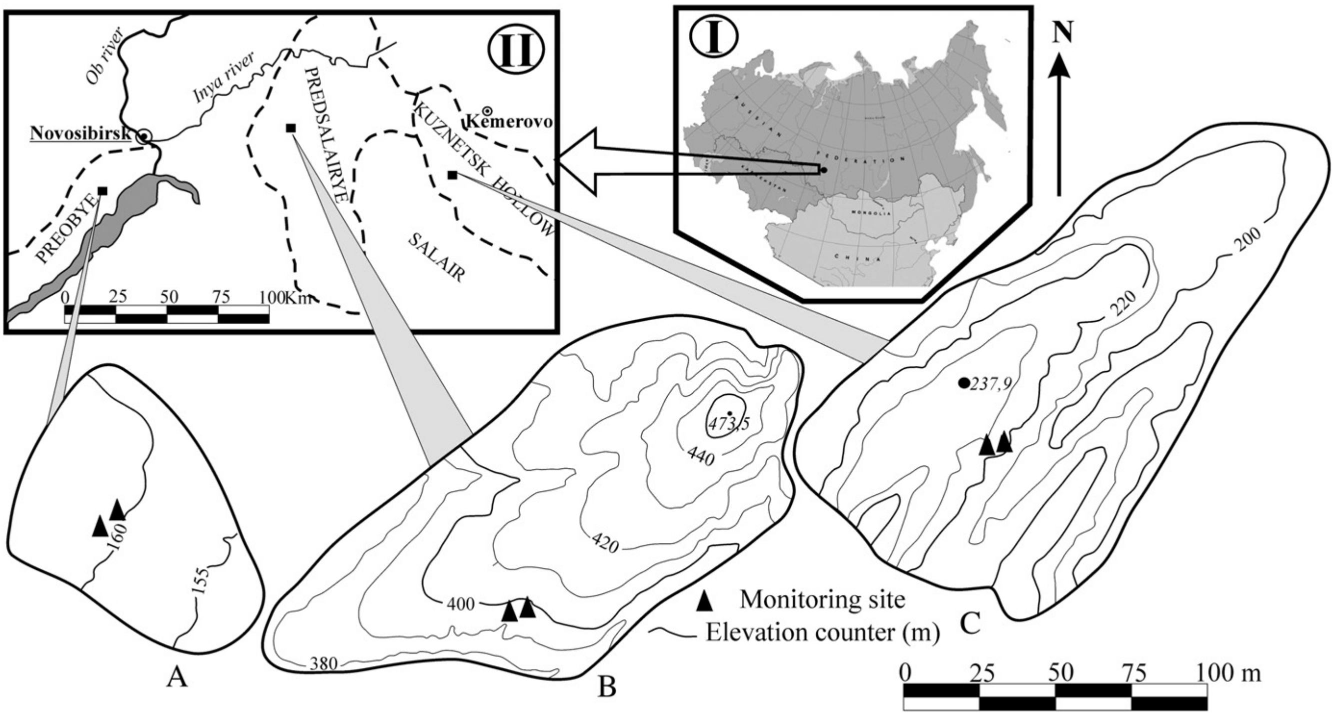

Fig. 1. Map of monitoring sites at Priobye (A), Predsalairye (B) and Kuznetsk hollow (C). The insert shows location of the study area in Russia (I), southern West Siberia (II).

(Ulen, 2003). In contrast to a period of rainfall, a period of snowmelt occurs for a prolonged amount of time and can be divided into three stages: initial, middle (or intensive) and final. These stages occur during the day as well over the period of snowmelt. Depending on the stage (Tanasienko, 2003), water discharge varies, and there is removal of whole soil aggregates, individual soil particles of different sizes (in the middle stage) and mainly finer particles (in the initial and the final stages). Not less than one-third of the total amount of runoff occurs during the initial and final stages. The ability of soil to resist the destructive influence of water flow depends on the level of soil particles <0.01 mm and the humus content (Brattacharyya et al., 2010; Lundekvam and Skøien, 1998; Tanasienko, 2002). Eroded plots are more vulnerable to destruction than non-eroded plots because of the reduction in the level of clay particles, which are responsible for the stability of soil aggregates (Stavi and Lal, 2011a, 2011b).

Despite the achievements in understanding the erosion process caused by rainfall, questions regarding snowmelt erosion remain poorly investigated. In particular, the effects of the relationships between sediments yield, snow water equivalent and water discharge on deep and long-term frozen soil are not well understood. The mechanism regulating the process of detachment and sedimentation of soil particles has also not been well studied. Field observations in zones of snowmelt erosion are scarce. With these issues in mind, the specific aims of the present study are to identify and assess runoff, variability in the suspended sediment concentration and differences in the textures of eroded soils and sediment particles on chernozem-type soils during years with different amounts of snow in southern West Siberia.

2. Materials and methods

2.1. Study area (relief and climate)

The study area is located in south-eastern West Siberia and is a zone of distribution of the most fertile chernozem-type soils and of intensive agriculture. This region includes Novosibirsk Predsalairye and Priobye (Novosibirsk area) and Kuznetsk hollow (Kemerovo area) (Fig. 1). These territories have different geomorphological and climatic characteristics and soils.

Predsalaiye is a flat, hilly plain and is highly incised. The plain is located in a forest–steppe zone. Arable land occupies more than 60% of all agricultural land, or approximately 800,000 ha; 23% of this territory is already eroded to a slight to moderate degree. Very high horizontal and vertical incision of the territory promotes erosive processes. Within Predsalairye, subareas with various degrees of erosion are easily distinguishable. The maximum demonstration of erosive processes in Predsalairye has been observed in the subarea called the Bugotac Hills, which represents a number of small hills that are extended in a north-eastern direction. The maximum hill height is 480 m above sea level. The horizontal incision of this territory is the greatest for Predsalairye and varies within 1.5–2.2 km km^{-1}; the vertical incision is 75–100 m. Owing to the strong incision of the territory, the basic elements are complex slopes with gradients of 9–12° near the watershed area and 25–30° closer to gullies. Convex slope forms prevail. Therefore, the greatest intensity of water discharge mainly occurs in the middle and bottom portions of the long slopes. Slopes in the southern direction are the steepest, while slopes in the northern direction are only slightly sloping and therefore less subject to erosive processes. The Bugotac Hills are classified as a territory having a very high risk of erosion.

Kuznetsk hollow is also located in the forest–steppe. The relief of Kuznetsk hollow is strongly incised. The horizontal incision varies from 0.6 to 0.8 km km^{-1} on the western extremity of the hollow and from 1.0 to 2.6 km km^{-1} in the rest of the territory. In some areas of the agricultural zone, the horizontal incision reaches 3.3–3.5 km km^{-1}. The vertical incision of the territory is in the same as that of Predsalairye (75–100 m). In connection with such essential incisions, the watersheds occupy approximately 20% of the territory. In the incised parts of the hollow, arable land occupies slightly more than 1 million ha; 15% of this territory is eroded to a slight to moderate degree.

Priobye is located in a transitive zone from forest–steppe to steppe. The distinctive features of the territory are the general elevation (absolute heights of 130–310 m), good natural drainage, absence of primary salinity and deep subterranean waters (10–15 m). The land of Priobye has a slight horizontal incision of 0.6–0.8 km km^{-1}. The watersheds have a flat shape and occupy 40% of the territory. The slope steepness near watersheds varies from 15 to 30 but reaches 15–30° near gullies, which indicates considerable erosive danger in the territory. From 180,000 ha of arable land, 15% is already eroded to a slight or moderate degree. Therefore, the given area is classified as a territory having a moderate risk of erosion.

The climate of West Siberia is continental, with cold winters and hot summers. It is characterised by sharp fluctuations in temperature and precipitation. Fluctuations in temperature between the coldest (January) and warmest (July) months can reach 90 °C. From November to March, approximately 25% of the total yearly precipitation falls (The Natural Resources of Siberia, 2007). In the studied areas, the amount of solid precipitation varies considerably, from 38 mm in Kuznetsk hollow to 256 mm in Predsalairye. Based on variations in the snow water equivalent (SWE) during the cold period, we classified hydrological years as follows: very low-snow, <75 mm; low-snow, 76–90 mm; normal, 91–105 mm; high-snow, 106–120 mm; and very high-snow, 121–180 mm (Tanasienko et al., 2009).

The average date of the first frost in the agricultural zone of West Siberia varies from September 5 in the north to September 20 in the south. Snow cover is formed gradually, after 2–3 melting periods in October, and sets in early November. Winter normally starts in early November, when the mean temperature falls below −5 °C, and there is persistent frost and snow. Snow cover usually lasts for 150–180 days. The greatest amount of snow cover occurs in March. In some years, steady snow cover only forms in the second half of November and disappears at the end of April. One feature of the study area, as well as the entire territory of West Siberia, is significant cooling of the air near the soil surface in the winter. The mean air temperature in the coldest month of January is occurs in southern West Siberia (−20.1–20.4 °C). Such air cooling causes prolonged soil freezing, especially for ploughed lands. Soil freezing begins in late October to early November and lasts through the winter. The depth of frost penetration is largely dependent on the timing of snowfall, soil moisture content and snow water equivalent in the winter (The Natural Resources of Siberia, 2007).

The freezing depth of ploughed soils of the steppe zone on the left bank of the Ob river reaches 1.5–2 m in the steppe zone, 1.1–1.2 m in the forest–steppe zone and no deeper than 0.6–0.8 m in the subtaiga zone. Among the three areas studied, the greatest freezing depth occurs at Priobye (Tanasienko et al., 2009). An icy layer is formed in the soil at a depth of 20–30 cm, an average moisture content at the time of freezing of greater than 20% and a soil temperature of approximately −2 °C. The soil thaws fully in the last ten days of May (The Nature of the Novosibirsk Region, 1968). It should be noted that the winter weather varies from year to year; in some years, it deviates significantly from the mean value. Spring begins in early April, when the radiation balance increases significantly. Rutkovskaya (1962) showed that in south-eastern West Siberia, during the period of snowmelt, the air temperature plays a major role in this process. According to the characteristics and synoptic conditions of spring weather and the predominance of one of two main melt factors, the spring periods of south-eastern West Siberia are divided into three types: 1) the radiative type, when snowmelt occurs in anticyclone conditions with clear, sunny weather and small negative night-time air temperatures; the average period of complete snow melting is 7–12 days; 2) the advective type, when snowmelt occurs due to the advection of warm air masses. This is mostly in the warm sectors of cyclones and partly on the western and northern peripheries of the anticyclone, during cloudy weather, when there is air temperature is above 0 °C, and direct solar radiation is absent. The average period of complete snow melting is 14–21 days; and 3) the mixed type, when snowmelt occurs due to the advection of warm air and radiation, cloudy weather and air temperatures above 0 °C alternating with clear weather, with slightly negative or positive air temperatures. The mixed type is divided into two subtypes: a) the advective–radiative, which is dominated by advective factors during the period of snowmelt; and b) the radiative–advective, which is dominated by radiative factors.

Different types of spring weather are characterised by changes in the duration of the snowmelt period. In years with a synchronous spring (radiative type of snowmelt) and a low snow water equivalent, sediment export begins on the second or third day after the start of snowmelt and lasts no more than 3–4 days. Early snowmelt explains the rapid settling of the snow and outcrops of soil spots on slopes. During a spring with particularly long duration, with a large SWE and a predominantly advective weather type, sediment export is significantly prolonged and occurs during 5–7 days of snowmelt.

The three stages of snowmelt are defined as the initial, middle (intensive stage) and final (Tanasienko, 2003). In the initial and final stages, water discharge is defined as not more than 2.5 l s ha^{-1}, or approximately 1 mm h ha^{-1}. These periods are characterised by low kinetic energy of a water flow. In the middle (intensive) stage, water discharge increases to more than 2.5 l s ha^{-1}. Snowmelt begins at approximately 10–11 a.m. The intensive stage begins at 12 p.m. The middle stage can last 2–4 h on a southern slope during the day and 8–10 h on a northern slope, where snowmelt does not stop, even at night. The intensive stage is characterised by the maximum kinetic energy of a water flow. The end stage lasts for 1–2 h.

2.2. Plot characteristics

Observations were made from 1969 to 1979 in Kuznetsk hollow, from 1980 to 1981 in Predsalairye and from 1984 to 1992 in Priobye. Since 1993, observations have only been made in Predsalairye. The runoff plots were set up each autumn (late October) after mouldboard ploughing to a depth of 22–24 cm. The construction technology of the runoff plot was described previously (Tanasienko et al., 2009).

The soils under study are classified as slightly eroded Haplic Phaeozems (Predsalairye) and Haplic Chernozems (Kuznetsk hollow and Priobye) (IUSS Working Group WRB, 2006). The soils are loessial loam. Slightly eroded soils occupied mainly the long slope at the trans-eluvial position (150–200 m from the watershed). The slopes were oriented in the southern and south-eastern directions with gradients of 2–3°. The mean depth of the humus horizon of slightly eroded chernozems was 25 cm for Predsalaiye, 25 cm for Priobye and 33 cm for Kuznetsk hollow. The amounts of total carbon (%) and calcium (millimoles (mmol) 100 g^{-1}) in the 0–20-cm layer of slightly eroded soils were 5.7% and 41.5 mmol, 4.6% and 32.0 mmol and 3.4% and 27.7 mmol for Predsalaiye, Kuznetsk hollow and Priobye, respectively. Soil textures are presented in Table 1.

The erosion resistance (ER) values of these soils differed and were determined by intrinsic characteristics, expressed in the quantitative and qualitative characteristics of humus, texture and the content of exchangeable cations of the soil. Each percentage of humus and humic acid bounds with free sesquioxides was considered a unit. The level of exchangeable calcium was expressed as a percentage of the soil mass; 1% is considered 10 units. The sum of all units was equal to the ER value (Tanasienko, 2002). Slightly eroded chernozems of Predsalaiye, Kuznetsk hollow and Priobye had 22.3, 25.6 and 18.1 units, respectively. The classification of Zaslavsky (1979) was used to assess soil loss during snowmelt erosion. This classification is based on a comparison of the rates of soil formation and soil loss. According to this classification, permissible soil loss on arable land is <2; slight loss

Table 1
Particle content (%) in slightly eroded Haplic Chernozems (0–20 cm) and suspended sediment (SS) in the surface runoff in years with different snow amounts.

Soil layer (0–20 cm), stages of snowmelt	1–0.05 mm (sand)			0.05–0.01 mm (large silt)			0.01–0.005 mm (medium silt)			0.005–0.001 mm (fine silt)			<0.001 mm (clay)			<0.01 mm		
	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
Soil	19.4	10.2	9.5	32.4	47.9	38.6	11.0	6.0	13.1	9.6	8.8	13.1	24.6	24.1	22.5	45.2	38.9	48.7
High-snow hydrological year																		
SS (I)	19.0	19.2	0.7	30.4	42.8	31.4	9.0	4.9	13.9	10.0	5.7	22.1	29.7	24.5	26.3	48.7	35.1	62.3
SS (M)	22.6	20.2	2.0	33.6	43.5	36.5	9.0	2.0	13.6	8.0	7.2	18.3	25.0	21.5	23.3	42.0	33.7	55.2
SS (F)	18.3	19.2	1.2	29.3	40.2	35.8	12.2	5.3	13.1	9.1	7.7	18.6	29.1	24.9	25.4	50.4	37.9	57.1
Low-snow hydrological year																		
SS (I)	ND*	5.2	8.1	ND*	45.2	27.2	ND*	7.5	17.5	ND*	12.0	18.8	ND*	27.1	23.3	ND*	46.6	57.6
SS (M)		12.1	9.8		47.7	31.7		5.4	17.2		8.4	15.6		23.8	21.5		37.6	54.3
SS (F)		9.4	5.6		49.7	27.2		4.8	17.5		9.8	20.0		23.8	25.2		38.4	62.7

I- initial; M- middle; F- final; A- Predsalairye; B- Preobye; C- Kuznetsk hollow; sum of particle (%) included loss from HCL treatment; ND*- not determined.

is 2–5, moderate loss is 5–10; strong loss is 10–20, very strong loss is 20–50, and extremely strong loss is >50 t ha^{-1}.

2.3. Measurements and analysis

The SWE was calculated using the snow-gauge BC-1 at each elementary watershed before the period of snowmelt (in most cases, March 25–30). Surface runoff and suspended sediment were studied in short- and long-term runoff plots that were 30–60 m in length and 10–15 m in width, with ordinary catchments that were 2–10 ha in area. Runoff water was collected manually at 1-h intervals in 1-l plastic jars in triplicate during the period of snowmelt to analyse the suspended sediment concentration (SSC). SSCs were determined by weighing the material present on the filters. The soil texture was measured according to a pipette method (Kachinski, 1958). When such studies began in the 1960s, the pipette method was the only method available to determine soil texture and suspended sediment. In recent years, we have used other methods, such as laser diffraction. However, there are differences in the measurements obtained by these different methods; therefore, all data presented in this study were obtained using the pipette method. This method requires 20 g of soil material. To obtain the required amount of suspended sediment in the initial and final stages of snowmelt, when the SSC is minimal, water samples were collected in 10-l plastic jars, or multiple samples were collected and pooled. The statistical methods (analysis of variance) of Dospekhov (1979) were used to process the SWE and SSC data.

3. Results and discussion

3.1. Runoff, soil loss and suspended sediment concentration

In the incised forest–steppe of West Siberia, on slightly eroded soils, considerable variations in runoff and soil loss were observed (Fig. 2). In Predsalairye and Kuznetsk hollow, in very low-snow years (SWE = 60 mm), there was no runoff observed. Over the observation period from 1969 to 2007, the prevalence of very low-snow winters was 21% in Predsalairye, 29% in Priobye and 16% in Kuznetsk hollow. In Priobye, even in very low-snow years, runoff was observed. Soil loss at this runoff level (24 mm) was less than 2 t ha^{-1} and was considered erosion-permissible (Zaslavsky, 1979). The prevalence of low-snow years (SWE = 80 mm) was 19%, 11% and 16% in Predsalairye, Kuznetsk hollow and Priobye, respectively. During these years, the soil loss in all studied areas varied by approximately 2 t ha^{-1}, a level that is also considered erosion-permissible. In normal years (SWE = 90–105 mm), which had a prevalence 22% in both Predsalairye and Priobye and 24% in Kuznetsk hollow, 60 mm of runoff led to a slight annual sediment yield (5–2 t ha^{-1}). The amount of surface runoff in high-snow years (SWE = 106–120 mm), which had a prevalence of 15%, 23% and 24% in Predsalairye, Priobye, and Kuznetsk

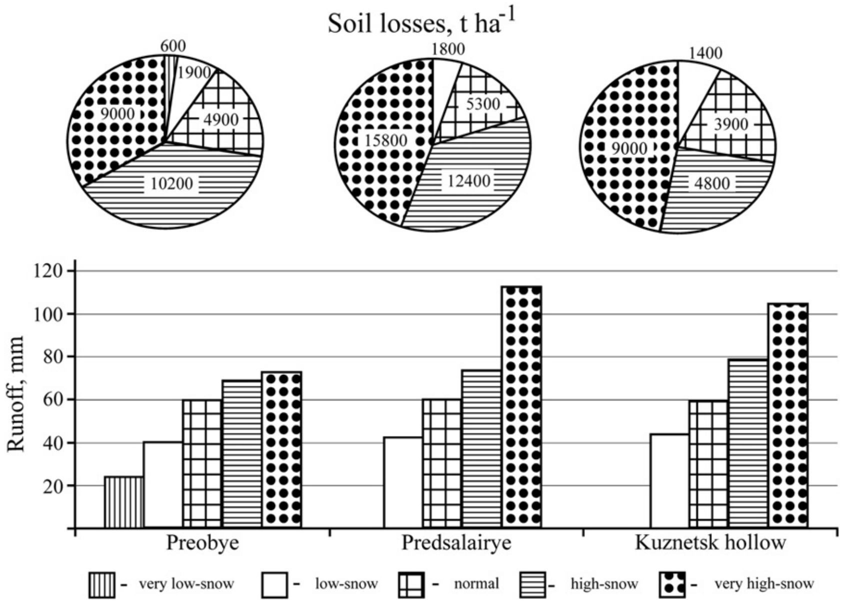

Fig. 2. Mean values of runoff and soil loss for the study catchments (slightly eroded chernozems, mouldboard fall-ploughed) in years with different snow amounts.

hollow, respectively, was approximately the same in all studied areas (70–79 mm) but led to different levels of soil loss. In Predsalairye, these losses were severe (>10 t ha^{-1}), in Priobye, they were moderate (approximately 10 t ha^{-1}), and in Kuznetsk hollow, they were slight (<5 t ha^{-1}). Very high-snow years (SWE >120 mm) occurred in Predsalairye, Kuznetsk hollow and Priobye with a prevalence of 15%, 24% and 23%, respectively. Runoff in these years led to strong soil loss (>15 t ha^{-1}) in Predsalaiye only. In the other areas, the soil loss was considered moderate. The increases in soil loss in years with higher snow water equivalents in Predsalaiye may be connected to the decreased erosion resistance of soils in this area because of the topography, which was generally at high risk of erosion.

Snowmelt periods in the three studied areas began at different times and had different durations (Fig. 3). Early snowmelt was typical of Priobye and it generally lasted ten days, with interruptions, when runoff was absent during two or three days owing to the negative daytime air temperatures. The daily concentration of suspended sediment varied from 5 to 17 g l^{-1}. The spring weather of this area was predominantly referred to as the advective type and advective–radiative subtype. In Predsalairye, the snowmelt began six days later. Interruptions in snowmelt were also typical for this area. However, the duration of the snowmelt period was less than seven days. The spring weather type in Predsalairye was predominantly referred to the advective–radiative subtype. The highest runoff rate and soil loss occurred within three days of snowmelt. The mean SSC in the intense stage of snowmelt varied from 16 to 42 g l^{-1}. The latest period of snowmelt occurred at Kuznetsk hollow. It started in the second half of April. The period of snowmelt in this area was short in duration, lasting only four days. The mean daily SSC varied from 5 to 33 g l^{-1}. The high SSC was mainly due to the large soil export over the course of one or two days and to the prevalence of the radiative type of spring weather.

The highest SSC was observed in years with large snow amount. Hourly and daily mean SSCs in the three areas during high-snow years are presented in Fig. 4A–C. In the initial stage of snowmelt, SSC varies from 0.1 to 10 g l^{-1}, depending on the area of study. The largest dispersion occurred in Predsalairye (0.4–10.0 g l^{-1}).

In the intense stage of snowmelt, water flow was characterised by a high SSC. The maximum concentrations were observed during the initial stage at Predsalairye (26.4–86.5 g l^{-1}; high-snow year). In Kuznetsk hollow, the SSC during this stage was from 3.2 to 20.4 g l^{-1} for high-snow and from 2.5 to 45.5 g l^{-1} for very high-snow years, respectively. The SSC in Priobye was from 0.5 to 30.7 for high-snow and from 1.3 to 36.1 g l^{-1} for very high-snow years. The final stage of snowmelt was characterised by similar SSC values as those found in the initial stage. In Predsalairye and Kuznetsk hollow, in comparison to Priobye, the length and steepness of slopes and the snowmelt duration were approximately equal, but the soils of these areas differed with respect to the humus content and, consequently, the erosion resistance (Tanasienko, 2002). The decreased soil erosion resistance of the chernozems of Predsalairye (ER = 22.3) compared to the chernozems of Kuznetsk hollow (ER = 25.6) contributed to the increase in SSC in Predsalairye. In Priobye, the significantly longer duration of snowmelt, the low gradient of land and long slopes minimised fluctuations in the runoff rate. In general, on chernozems of West Siberia, runoff with high SSC represented an average of 66% of the total runoff, or 69 mm. Consequently, 34% of the runoff occurred during the initial and final stages of snowmelt. The main soil loss occurred during the middle stage of snowmelt, when 1 mm (or 10 m^3 ha^{-1}) of runoff transported 35–150 kg ha^{-1} of soil material.

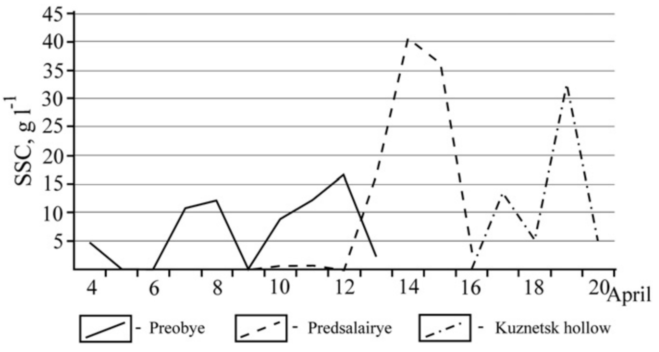

Fig. 3. Dynamics of the mean daily suspended sediment concentration (SSC) in high-snow years.

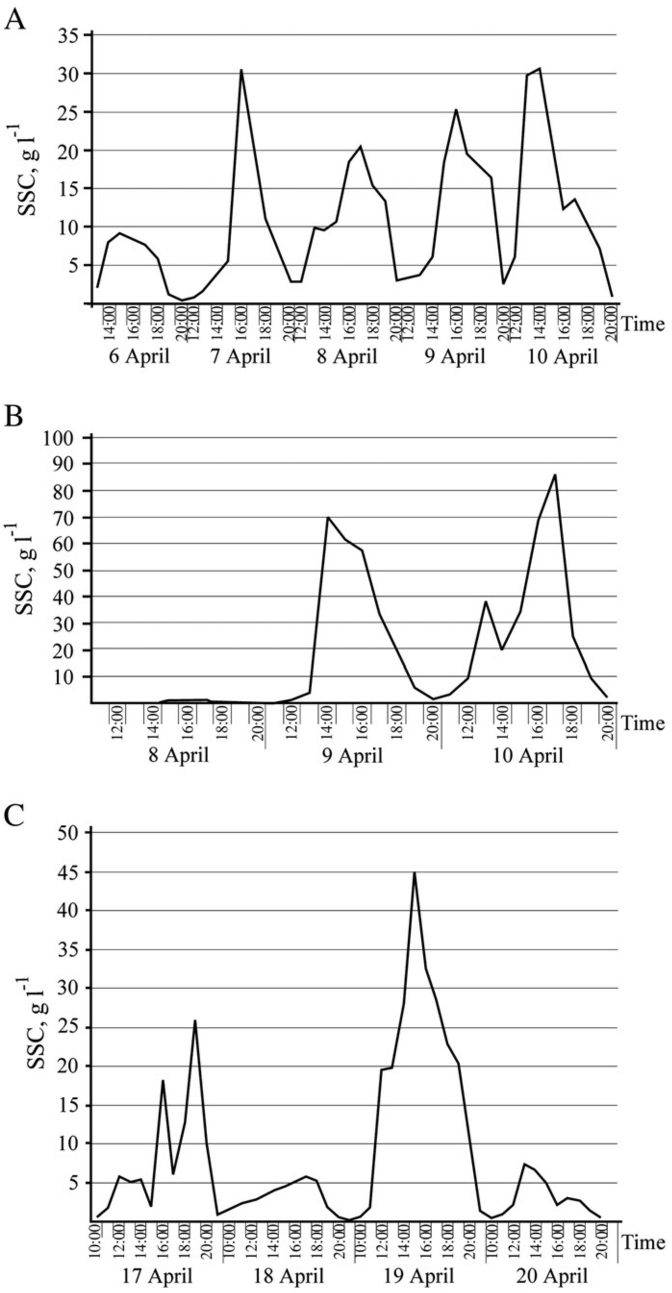

Fig. 4. Dynamics of the hourly suspended sediment concentration (SSC) at Priobye (A), Predsalairye (B) and Kuznetsk hollow (C) in high-snow years.

3.2. Texture of eroded soils and suspended sediment

Differences in the texture of the eroded chernozems (0–20 cm) of the studied areas were reflected in the textures of the suspended sediments (Table 1). The chernozem texture was silty clay loam in Predsalairye and Kuznetsk hollow and loam in Priobye. The amount of clay present was nearly equal among the three regions (22–24%). Chernozems of Priobye had a large percentage of large silt (48%). The percentages of large silt in the chernozems of Predsalairye and Kuznetsk hollow were from 33 to 39%. The ploughed layer of chernozems of Priobye contained almost 2-fold less sand than the chernozems of Predsalairye.

The percentage of particles <0.01 mm in the SS in Predsalairye and Kuznetsk hollow were generally 5–13% higher than in the ploughed layer. In Kuznetsk hollow, the SSC was 9–13% greater than in the ploughed layer during the initial and final stages of snowmelt and 6–7% greater in the middle stage. Suspended sediment in Predsalairye contains 3–5% more clay particles than in the ploughed layer. In the middle stage of snowmelt in Predsalairye, there was no difference in the texture of SS and the ploughed layer. Chernozems of Priobye were characterised by a lower level of particles <0.01 mm in SS than for Predsalairye and Kuznetsk hollow. Only in low-snow years does the removal of these particles obey the pattern characteristic of these areas. In high-snow years, the level of particles <0.01 mm in SS during any stage of snowmelt was less than their levels in the ploughed layer. The increased level of large silt in the soil of Priobye was thought to increase the sediment yield because the loess particles, presented mainly by large silt, reduces the water resistance of soil (Kværnø and Øygardena, 2006), but we did not observe this phenomenon during high-snow years. It is difficult to interpret the reduced removal of sand from the chernozems of Kuznetsk hollow during all stages of snowmelt in high-snow years. Thus, the data obtained require further research. The spring weather in each area affects removal of soil particles. In Kuznetsk hollow, which has a very short and rapid snowmelt, even in the middle stage, a large amount of particles <0.01 mm were removed, whereas in Predsalairye and Priobye, which have prolonged snowmelt periods, the amounts of such particles in the suspended sediment were less than in the ploughed layer. In general, we can conclude that the chernozems of West Siberia are characterised by increasing amounts of particles <0.01 mm in the suspended sediment at the initial and final stages of the period of snowmelt compared to the ploughed layer of eroded soil.

Soil particles <0.01 mm, particularly colloidal particles, are responsible for the formation of agronomically valuable soil structure and water-resistance aggregates (Gedroits, 1955). In addition, soil particles <0.01 mm are enriched with organic matter. The loss of these particles during snowmelt decreases considerably fertility of soil and makes recently eroded plots more vulnerable to further destruction.

The level of clay export in different hydrological years is shown in Fig. 5. In very low-snow years, soil loss was observed only in Priobye, and it was within the permissible rate of soil loss; the level of clay removal was low. In low-snow years, when runoff was equal to 40–42 mm, the level of clay removal was 300–500 kg ha^{-1}. In normal hydrological years, clay loss was 3-fold higher. In high-snow years when runoff was 70–80 mm, only clay removal exceeded the permissible rate of erosion loss for soil. Due to their greater resistance to erosion, the chernozems of Kuznetsk hollow lost less clay than the chernozems of Predsalairye and Priobye in all studied years. The greatest clay losses occurred in Predsalairye.

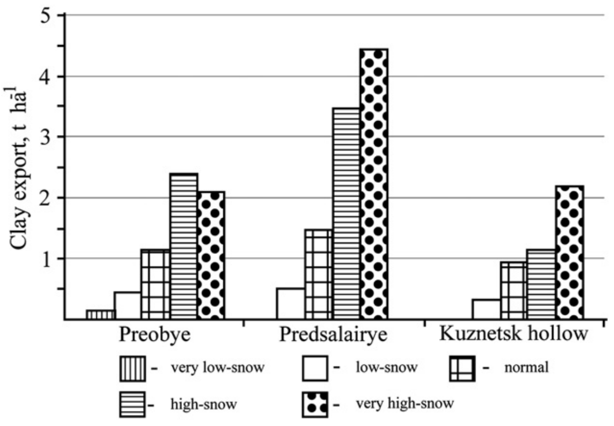

Fig. 5. Clay export in years with different amounts of snow.

4. Conclusions

1. Significant damage to the arable lands of southern West Siberia causes surface runoff as a result of snowmelt. The runoff in incised areas of West Siberia that are forest–steppe is considered permissible for the ecosystem during very low-snow and low-snow years. In such years, the suspended sediment yield did not exceed 2 t ha^{-1}. After winters with normal amounts of snow, the runoff led to slight soil loss. Soil losses in high-snow and very high-snow years varied from slight to severe (4.8–15.8 t ha^{-1}). Among the three studied areas, the greatest erosive danger was in Predsalairye due to the low erosion resistance of the soils there.
2. For the chernozems of West Siberia, runoff with a high suspended sediment concentration represented approximately 66% of the total runoff, or 69 mm, and 34% of runoff occurred during the initial and final stages of snowmelt. The greatest degree of soil loss occurred in the middle of the snowmelt period, when 1 mm (or 10 m^3 ha^{-1}) of runoff transported 35–150 kg ha^{-1} of soil material. The texture of suspended sediment was dependent on the particle content in the eroded layer, the snow water equivalent, the stage of snowmelt, the relief features and the spring weather characteristics.
3. In the initial and final stages of snowmelt, the removal of particles <0.01 mm was most dominate. The suspended sediment consisted of up to 60% fine particles, most of which were represented by clay. The total clay removal by runoff from the ploughed layer in high-snow and very high-snow years varied from 3300 to 4200 kg ha^{-1} of which 1260–1500 kg ha^{-1} of losses occurred during the initial and final stages of snowmelt. The information presented therefore emphasises the need to develop the effective measures for soil prevention. In particular, it can be application of mineral “glue” making the soil aggregates more water-resistant.

References

Bhattacharyya, R., Smetsb, T., Fullen, M.A., Poesen, J., Booth, C.A., 2010. Effectiveness of geotextiles in reducing runoff and soil loss: A synthesis. Catena 81, 184–195.

Cray, D.M., Toth, B., Zhao, L., Pomeroy, J.W., Granger, P.J., 2001. Estimating areal snowlelt infiltration into frozen soils. Hydrol. Process. 15, 3095–3111.

Dangler, E.W., El-Swaify, S.A., 1976. Erosion of selected Hawaii soils by simulated rainfall. Soil Sci. Soc. Am. J. 40, 769–773.

Deelstra, J., Kvaerno, S.H., Granlund, K., Seleika, A.S., Gaigalis, K., Kyllmar, K., Vagstad, N., 2009. Runoff and nutrient losses during winter periods in cold climates — requirements to nutrient simulation models. J. Environ. Monit. 11, 602–609.

Dospekhov, V.A., 1979. Field Experiment Technique (with statistics of researches). Kolos, Moscow (in Russian).

Gedroits, K.K., 1955. Selected Proceedings, vol. 3. Moscow (in Russian).

IUSS Working Group WRB, 2006. World Reference Base for Soils Resources. FAO, Rome.

Iwata, Y., Hayashi, M., Suzuki, S., Hirota, T., Hasegawa, S., 2010. Effects of snow cover on soil freezing, water movement, and snowmelt infiltration: a paired plot experiment. Water Resour. Res. 46, W09504.

Kachinski, N.A., 1958. Mechanical and microagregate composition of soil: methods. AS USSR, Moscow (in Russian).

Khmelev, V.A., Tanasienko, A.A., 2009. Soil resources of the Novosibirsk region and ways of their rational use. SB RAS Publisher, Novosibirsk (in Russian).

Kværnø, S.H., Øygardena, L., 2006. The influence of freeze–thaw cycles and soil moisture on aggregate stability of three soils in Norway. Catena 67, 175–182.

Lal, R., 1976. Soil erosion on Altisol in Western Nigeria. IY. Nutrient element in runoff and eroded sediment. Geoderma 16, 403–417.

Lal, R., 2005. Soil erosion and carbon dynamics. Soil Tillage Res. 81, 137–142.

Lundekvam, H., Skøien, S., 1998. Soil erosion in Norway. An overview of measurements from soil loss plots. Soil Manag. 14, 84–89.

Nord, G., Esteves, M., 2010. The effect of soil type, meteorological forcing and slope gradient on the simulation of internal erosion processes at the local scale. Hydrobiol. Process. 13, 1766–1780.

Oztas, T., Fayetorbay, F., 2003. Effect of freezing and thawing processes on soil aggregate stability. Catena 52, 1–8.

The Nature of the Novosibirsk Region. In: Popolzin, A.G. (Ed.), West Siberian Published House, Novosibirsk (in Russian).

Rutkovskaya, N.V., 1962. Snowmelting in the southeastern part of West Siberian plain. In: Rikhter (Ed.), Blanket of snow: distribution and role in national economy. USSR Acad. Sci., Moscow, pp. 104–113 (in Russian).

Stavi, I., Lal, R., 2011a. Variability of soil physical quality and erodibility in a water-eroded cropland. Catena 84, 148–155.

Stavi, I., Lal, R., 2011b. Variability of soil physical quality in uneroded, eroded, and depositional cropland sites. Geomorphology 125, 85–91.

Steegen, A., Govers, G., Beuselinck, L., Nachtergaele, J., Takken, I., Poesen, J., 1998. Variations in sediment yield from an agricultural drainage basin in central Belgium. Final Proc. Int. Sym. Modelling soil erosion, sediment transport and closely related hydrological processes. Vienna, pp. 177–185.

Tanasienko, A.A., 2002. The resistance of West Siberian chernozems to erosion. Eur. Soil Sci. 11, 1380–1389.

Tanasienko, A.A., 2003. Specific features of soil erosion in Siberia. SB RAS Publisher, Novosibirsk (in Russian).

Tanasienko, A.A., Yakutina, O.P., Chumbaev, A.S., 2009. Snowmelt runoff parameters and geochemical migration of elements in the dissected forest-steppe of West Siberia. Catena 78, 122–128.

The Natural Resources of Siberia: territorial locality and economic evaluation, 12. Novosibirsk (in Russian).

Ulen, B., 2003. Concentration and transport of different forms of phosphorus during snowmelt runoff from an illite clay soil. Hydrol. Process. 17, 747–758.

Yamazaki, Y., Kubota, J., Ohata, T., Vuglinsky, V., Mizuyama, T., 2006. Seasonal changes in runoff characteristics on a permafrost watershed in the southern mountainous region of eastern Siberia. Hydrol. Process. 20, 453–467.

Zaslavsky, M.N., 1979. Soil erosion. Mysl, Moscow (in Russian).