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Contribution of climate and land cover changes to reduction in soil erosion rates within small cultivated catchments in the eastern part of the Russian Plain during the last 60 years

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ABSTRACT

The eastern part of the Russian Plain is an important agricultural region of European Russia with high proportion of cultivated lands in the steppe, forest-steppe and forest (southern part) landscape zones. Soil erosion is the main process of land degradation and surface water contamination there. Climate and land cover changes have been observed in this region during the last 30 years. However, field quantitative assessments of soil erosion rates are not available for the eastern part of European Russia due to the lack of monitoring data as well as the evaluation of erosion/deposition processes in cultivated catchments using other field methods. Three representative small cultivated catchments with high (> 80%) proportion of cultivated lands were selected in the forest (southern part), forest-steppe and steppe zones of the study region to evaluate sedimentation rates in dry valley bottoms of the catchments for two-time intervals (1963–1986 and 1987–2016) based on the application of the bomb-derived and Chernobyl-derived ^{137}Cs isotope for sediment dating. The 3–4 depth ^{137}Cs profiles were used to assess the sedimentation rates within the each investigated catchment. It was established that the sedimentation rates have considerably decreased (at least 2–3 times) over the last 30 years compared to 1963–1986 in all the investigated catchments. This is in agreement with results of erosion rate calculations using erosion models for the forest zone, however not consistent with erosion rates assessments for the forest-steppe and steppe zones. According to the model calculations, erosion rates show a slight decrease in the forest-steppe zone and increase in the steppe zone. The reduction in surface runoff during snowmelt period is one of the reasons for decrease in erosion rates within cultivated slopes for all the investigated catchments. The increase in proportion of perennial grasses in the regional crop rotation is another important reason for the decrease in erosion rates for the catchment located in the south of the forest zone. The importance of land cover changes in a major decrease of soil losses from the cultivated fields of the investigated catchments located in the forest-steppe and steppe zones cannot be identified due to the lack detailed information about crop rotation for those particular sites. However, available regional information about crop rotation changes for the two-time intervals (1960–1980 and 1996–2012) do not explain very high reduction in sedimentation rates in the dry valley bottoms after 1986.

1. Introduction

It is well-known that soil degradation is one of the main threats to sustainable development of agriculture. Soil erosion is one of the main process responsible for land degradation, leading to high financial losses due to reduction of soil productivity (Pimentel, 1993; Uri and Lewis, 1998; Podmanicky et al., 2011), for lateral migration of mineral fertilizers, pesticides, heavy metals and other substances transported with sediments, eventually leading to contamination of soils located in different sediment sinks along pathways from cultivated slopes to river channels (Mullan and Favis-Mortlock, 2011), surface water pollution (Collins et al., 2012), siltation of ponds and reservoirs (Boardman et al., 2009) and eutrophication of terrestrial waterbodies (Morgan, 2009) and so on. Attempts to estimate the intensity of erosion rates under the global (and regional) climate change (Favis-Mortlock and Mullan, 2011; Mullan, 2013; Routschek et al., 2014) and land use changes (Govers et al., 2006; Cebecauer and Hofierka, 2008; Latocha et al., 2016; Golosov et al., 2017a; Vanwalleghem et al., 2017) were made for the different parts of Europe using a combination of erosion models and GIS analysis. The application of various tracers (fallout radionuclides,

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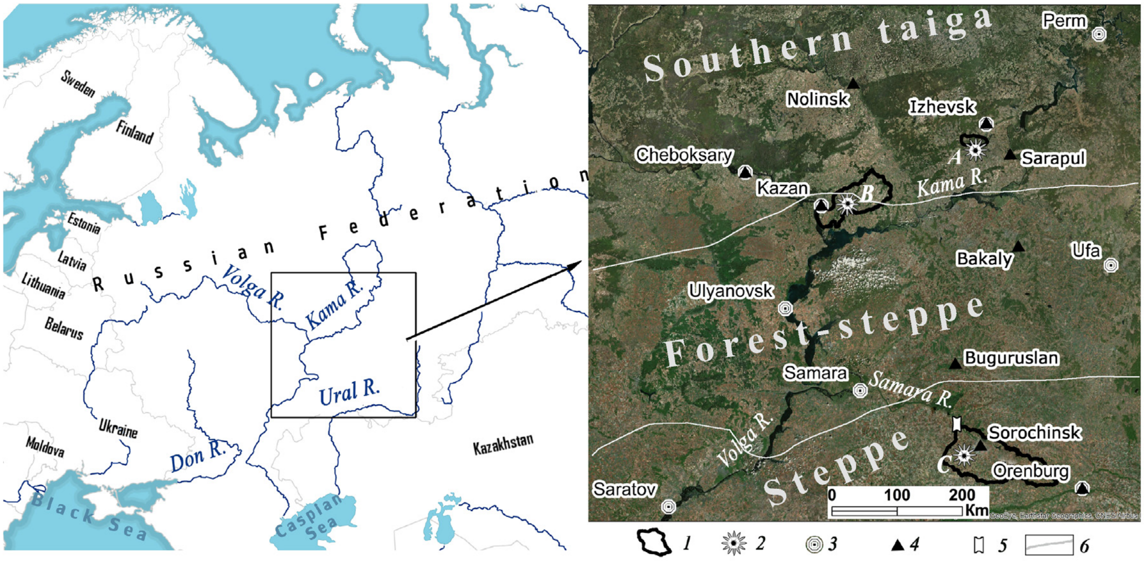

Fig. 1. Location of the investigated small catchments in the eastern part of the Russian (East European) Plain. *1* – the boundaries of the river basins which includes the catchments; *2* – the small catchments (*A* – Kuregovo, *B* – Temeva Rechka, *C* – Pogromka); *3* – the regional centers (cities); *4* – the weather stations; *5* – the Samara River hydrological gauging station at the village of Yelshanka (Orenburg Oblast, Russia); *6* – the boundaries of the landscape zones of the Russian Plain (according to National Atlas of Soils of the Russian Federation, 2011).

spherical magnetic particles etc.) also allowed to estimate recent trends in erosion rates in small catchments (Zapata, 2002; Mabit et al., 2008; Olson et al., 2008; Belyaev et al., 2009; Gennadiev et al., 2010; Porto et al., 2011, 2014; Golosov et al., 2011, 2017b; Gusarov et al., 2018, and others). Also, the dynamics of erosion processes within river basins is evaluated based on the analysis of the monitoring data on water discharges and sediment yield of regional rivers (Gusarov, 2001; Walling and Fang, 2003; Dedkov and Gusarov, 2006; Syvitski and Kettner, 2011; Vanmaercke et al., 2012, and others). In other studies, practical issues were considered to the analysis of the soil erosion effect on agricultural land productivity under the recent climate and land use changes (Bakker et al., 2008; Foucher et al., 2014, and others), sediment-associated pollutants lateral migration and their influence on the environment (Ayrault et al., 2014; Desmet et al., 2012, and others). Both rainfall erosion during the warm period of year (since the second half of April till October) and erosion during snowmelt (March and the first half of April) are observed in European territory of Russia (ETR), where the last decades are characterized by significant climate and land use changes (Shmakin and Popova, 2006; Adam et al., 2009; Choi et al., 2010; Popova and Polyakova, 2013; Madsen, 2014; and others). The climate change has contributed to an increase in air temperature in the winter months, and, as a consequence, a decrease in the depth of freezing of regional soils (Park et al., 2014). As a result, the surface runoff from the cultivated slopes during spring snowmelt decreased in the different landscape zones of European Russia from 23 to 49 mm in 1959–1981 up to 1–9 mm during the last 2–3 decades according to the monitoring observations on the runoff plots (Barabanov et al., 2018). It coincides with change of the intra-annual water flow redistribution in favor of decreasing of proportion of spring flood in the river flow with a simultaneous growth of lower water flow during summer time (Frolova et al., 2015). According to the erosion model, calculations undertaken for the entire ETR, the annual erosion rates have reduced in the forest and forest-steppe landscape zones during the period 1991–2015 as compared to the period 1960–1980 by 1.3–1.8 times: from 7.3 and 4.3 Mg ha^{-1} yr^{-1} to 4.1 and 3.3 Mg ha^{-1} yr^{-1}, respectively (Golosov et al., 2017a). At the same time, the erosion rates in the steppe zone, on the contrary, have increased by 1.2 times, from 3.9 to 4.6 Mg ha^{-1} yr^{-1}. Unfortunately, there are no available results of field investigations of erosion rates during the last 30 years for the eastern part of the ETR. So, it is not possible to verify the results of the erosion model calculations. The national soil erosion surveys carried out in all regions on a regular basis until 1991, are no longer undertaken since the USSR collapse. One of the possibility to identify a trend in the mean soil erosion rates for the two-time intervals is to define sedimentation rates on dry valley bottoms of first-order agricultural catchments using the bomb-derived and Chernobyl-derived ^{137}Cs fallouts for sediment dating (Golosov et al., 2006; 2017b). The sedimentation rates in sediment sinks located nearby from cultivated fields are directly proportional to intensity of sheet, rill and gully erosion in the catchment area. This approach can be used to identify a trend in soil erosion rate changes on croplands (Porto et al., 2016; Golosov et al., 2017b). Nevertheless, methodologically it is still difficult to evaluate the erosion rates on the slopes only using data on the dynamics of sedimentation rates, unless a catchment is not a closed system (lake, reservoir, pond, etc.) intercepting almost all the sediments.

The objective of this study are to define a trend of the changes in soil erosion rate for the two-time intervals (1963–1986 and 1986–2015) within the most agriculturally developed regions of the eastern part of the ETR based on detailed evaluation of sedimentation rates in the valley bottoms of selected first-order small agricultural catchments located in the forest, forest-steppe and steppe zones of this region, and to evaluate the contribution of climate and land cover changes to the revealed changes in soil losses.

2. Material and methods

2.1. Study area

Three small catchments located in different landscape zones in the eastern part of the ETR (the east part of the Volga River basin) were selected for detail investigation (Fig. 1) based on the following principles. Firstly, the area of cultivated lands on the catchments should exceed 80% and has not been considerably changed since the mid-1950s. Secondly, the relief of the catchments should be similar to the region type of relief. All the regions of the ETR investigated were affected by global warming with an increase in winter air temperatures according to meteorological observation data (Table 1). The lithology of the catchments is deluvium/solifluction loams of the Late Quaternary, lying on the multifarious complex of marine and terrigenous deposits of the Late Paleozoic and Early Mesozoic of the sedimentary cover of the