Preliminary estimating the contemporary sedimentation trend in dry valley bottoms of first-order catchments of different landscape zones of the Russian Plain using the $^{137}$Cs as a chronomarker

A Sharifullin A Gusarov, A Gafurov and B Essuman-Quainoo

Institute of Environmental Sciences, Kazan Federal University, 18, Kremlyovskaya str., 420008, Kazan, Russia

E-mail: AGSharifullin@kpfu.ru, avgusarov@mail.ru

Abstract. A general trend of erosion processes over the last 50–60 years can be estimated by dating sediments washed off from arable lands and accumulated in the first-order dry valleys bottoms. Three small (first-order) catchments were chosen as objects of the study. They are located, respectively, in the southern part of the taiga zone, the zone of temperate broad-leaf forests and the forest-steppe zone of the Russian Plain. To date the sediments accumulated in the bottoms the radioactive caesium-137 ($^{137}$Cs) of global (since 1954) and Chernobyl origin (1986) had been used as a chronomarker. The average (for all the catchments) sedimentation rates during the global $^{137}$Cs fallout period (1963(1954)–1986) are at least 0.88–2.71 cm per year. For the period that has passed since the Chernobyl accident (1986–2015(2016)) the average rates were 0.15–1.07 cm per year. The greatest reduction in the sedimentation rates is observed in the subzone of the southern taiga, the lowest one is in the forest-steppe zone of the Russian Plain. The main reason for such significant reduction in the rates of sedimentation of the soil erosion products in the dry valley bottoms was a reduction of surface runoff within the catchments during a snowmelt period, as well as crop-rotation changes there.

1. Introduction

The monitoring of erosion/accumulation processes within agricultural lands of Russia has not been implemented in recent decades due to high financial costs. Therefore, the actuality of estimating the processes increases year by year. This paper takes a look at the accumulation rates estimation of the soil/ground particles washed off from the catchment slopes, using the caesium-137 ($^{137}$Cs) as a chronomarker. It was made on the example of some catchments within the forest and forest-steppe zones of the Russian Plain. The approach has been applied by various researchers in many regions of the World [1–7 etc]. The caesium-137 is an artificial origin isotope which appeared in the environment from the beginning of nuclear testing in 1954. There are $^{137}$Cs of global fallout throughout the Earth with atmospheric precipitation during the nuclear tests (figure 1) in the atmosphere (with the extreme fallout in 1963), and the Chernobyl-derived$^{137}$Cs associated with the accident at the Chernobyl nuclear power station (April–May, 1986), fell mainly in Eastern and Central Europe, Scandinavia.
According to modern research [4], the extreme concentration of the Chernobyl-derived $^{137}$Cs persists in a soil depth of 10–20 cm, and, depending on the granulometric composition of the soils, can migrate at different rates (from 0 to 0.35 cm per year) [9–13] during first years.

Figure 1. The $^{137}$Cs fallout in the Northern hemisphere (1) [4] and the Leningrad Region of the former USSR (2) [8].

Figure 2. Location of the catchments under study in the Russian Plain. The catchments: 1 – the Kuregovo (the Udmurt Republic), 2 – the Temeva Rechka (the Tatarstan Republic), 3 – the Veduga (the Voronezh Region); RB – the river basins.
Table 1. Some morphometric parameters of the catchments and their dry valleys.

| The parameters | The catchments          |
|---------------|-------------------------|
|               | Kuregovo | Temeva Rechka | Veduga |
| Catchment area, km² | 0.68     | 1.13     | 1.15   |
| Average absolute height, m | 167      | 161      | 177    |
| Altitude amplitude, m | 76       | 74       | 43     |
| Dry valley length (with the hollows), m | 400 (680) | 1635 (2087) | 1183 (1463) |
| Dry valley bottom area, km² | 0.006    | 0.024    | 0.020  |

2. Study area

To assess the erosion/sedimentation intensity trend, three key dry valley catchments located in different landscape zones of the Russian Plain, from the southern taiga to the forest-steppe zone, were selected: the Kuregovo catchment within the Agryzka River basin (the Udmurt Republic), the Temeva Rechka catchment within the Myosha River basin (the Republic of Tatarstan) and the Veduga catchment within the Veduga River basin (the Voronezh Region) (figure 2). The surfaces of the catchments under study are formed on quaternary deluvium/solifluction loams in the case of the Kuregovo and the Temeva Rechka, and on quaternary loess in the case of the Veduga.

The lengths of the dry valley bottoms of the catchments vary from 400 to 1635 m (table 1). Moreover, the Temeva Rechka catchment is dissected by a dense network of gentle hollows (up to 1.5 km long); the Veduga catchment has the same land forms only on its left side, and in the Kuregovo catchment the hollows are sporadic. There are several small erosion head-cuts (up to 0.5 m deep) in the dry valley bottoms of the catchments located in the Republic of Tatarstan and the Udmurt Republic. The average absolute heights in the key catchments vary from 161 to 177 m (table 1). The climate type is temperate continental with mean annual temperature from 2.7 °C in the Udmurt Republic (in the southern taiga subzone with coniferous and coniferous-deciduous forests) through 4.6 °C in the Tatarstan Republic (the temperate broad-leaf forests zone) to 7 °C in the Voronezh Region (the forest-steppe zone). The distribution of atmospheric precipitation over the territory of the Russian Plain depends on the western air masses transfer. The mean annual precipitation in all three key catchments varies from 522 mm (the catchment in the Udmurt Republic) through 553 mm (the Temeva Rechka catchment) up to 559 mm (the catchment in the Voronezh Region).

The most of the precipitation (66–74%) fall during the warm period (April–October). Over the past 30 years the precipitation increased in total amount in all the regions studied, as well as the number of rainfalls exceeding 10 mm, which can create surface runoff, increased.

Sod-podzolic soils (Umbric Albeluvisols Abruptic (WRB, 2006)) are predominant within the Kuregovo catchment, gray forest soils (Greyic Phaeozems Albic (WRB, 2006)) – within the Temeva Rechka catchment, and chernozems (Haplic Chernozems (Arlic, Pachic) and Luvic Chernozems (WRB, 2006)) – within the Veduga catchment.

All the catchments studied are well ploughed (ploughed lands are more than 80% of total catchment area). Also, there are agricultural fields located very close to the dry valleysbrows. In the course of the last decades, even after the USSR collapse, according to Landsat space images, the ploughed areas were not abandoned.

3. Materials and methods

At each of the key catchments, the high-resolution aerial survey was carried out using unmanned aerial vehicle DJI Phantom 4 followed by the generation of digital elevation model (DEM) of the catchments (including their dry valleys). Various catchment elements such as the cropland/grassland borders, the hollows, the erosion cuts, furrows, runoff paths were extracted from the DEM. Based on obtained results, 3–4 soil (Stratozems (WRB, 2006)) sections (pits) were prepared in each of the dry valley bottoms (in different parts of the bottoms according to the peculiarities of sedimentation and sediment transit there).
In each section (pit), layer-by-layer soil samples from fixed area (15×15 cm, 10×10 cm) were vertically taken through 2, 3, 5 cm for the following 137Cs-activity analysis.

The specific 137Cs activity in the soil samples was determined using a coaxial germanium γ-spectrometer at the research laboratory of soil erosion and riverbed processes of the Lomonosov Moscow State University (Russia). Previously, all the soil samples were dried to an absolutely dry state at a temperature of 105°C and sieved through a sieve with a hole diameter of 1 mm. Based on results of the laboratory analysis, diagrams of the 137Cs vertical distribution were constructed and the mean annual sedimentation rates for two time intervals (1963(1954)–1986 and 1986–2015 (2016)) were calculated.

Simultaneously, the meteorological data (for the period 1950–2015) have been collected for several weather stations located in the vicinities of the catchments under study in the cities of Kazan, Nolinsk, Sarapul, Cheboksary, Bakaly, Voronezh, Stary Oskol and Izhevsk to identify some regional features of the hydrometeorological characteristics changes (the materials from the All-Russian Research Institute of Hydrometeorological Information – World Data Center, ARRIHI–WDC; http://meteo.ru).

4. Results

In the course of detailed investigation of the dry valleys and description of the soil sections (pits) it was established that the bulk of the deposits accumulated in the dry valley bottoms comes from the ploughed lands due to sheet/rill erosion. Also, an additional source of the sediments was the material formed due to the receipt of the material from the gullies formed on the left side of the Veduga catchment and due to the erosion head-cuts within the catchments of Kuregovo and Temeva Rechka, mainly in the period until 1986.

The 137Cs distribution in all the catchments under study is not the same. The greatest concentrations are observed in the Voronezh Region and the Udmurt Republic (figure 3), since in these areas, despite their different distance from the Chernobyl nuclear power station, a greater amount of the 137Cs fell out in May 1986 immediately after the accident.

The Chernobyl-derived 137Cs peak (1986) is quite clearly distinguished in the bottom sediments of all the dry valleys under study. The global 137Cs peak (1963) is not defined so clearly on the depth distribution curves except the Temeva Rechka catchment (figure 3). The main reason for these peaks absence is a linear erosion of the sediments in the bottoms of the dry valleys and subsequent sediment redeposition occurred before 1986, and also, in some cases, insufficient depth of sampling for the 137Cs content determination. That is why the accuracy of determining the sedimentation rates during the period 1963–1986 in the catchments of Kuregovo and Veduga was lower than for the period 1986–2015(2016).

It was estimated taking into account the vertical 137Cs migration which is approximately 0.35 cm per year during first 3–4 years with following reduction to 0.1 cm per year [5, 7], and the lower horizons are conventionally dated as potentially close to 1954, that is, in fact, the sedimentation rates were somewhat underestimated. In the Kuregovo catchment located in the subzone of the southern taiga it is established that the mean annual sedimentation rates were at least 1.8–2.5 cm per year and 0.15–0.75 cm per year for periods 1954(1963)–1986 and 1986–2015(6) respectively. In the zone of temperate broad-leaf forests (the Temeva Rechka catchment) the rates were 0.92–1.81 and 0.17–0.50 cm per year respectively; in the forest-steppe zone (the Veduga catchment) the rates were 0.88–2.71 and 0.47–1.07 cm per year, respectively. So, the greatest reduction in the average sedimentation rates is observed in the subzone of the southern taiga, the lowest one is in the forest-steppe zone of the Russian Plain.

This sedimentation trend was primarily determined by the climate change in the region, as well as changes in crop rotation. The climate change has affected the reduction of surface runoff from the slopes during the snowmelt period, caused by an increase in air temperature and a decrease in a soil freezing depth in winter [14]. An agricultural activity impact on the reduction of the sedimentation (erosion) rates in all the dry valley bottoms (catchments) under study was not so significant, with the exception of the Kuregovo catchment, where the percentage of perennial grasses incrop-rotation structure has been increasing since the 1990s.
Figure 3. The vertical distribution of the $^{137}$Cs concentration and sedimentation rates at the soil (sediment) sections (pits) within the dry valleys of the catchments under study.

The catchments: A – the Veduga (the Voronezh Region), B – the Temeva Rechka (the Tatarstan Republic), C – the Kuregovo (the Udmurt Republic); the average sedimentation rates for:

$r_1$ – 1954(?)–1963, $r_2$ – 1963–1986, $r_3$ – 1986–2015(2016);

$h$ – the depths of soil (sediment) samples selection ($h_{\text{max}}$ – the maximal depth of the selection)

**Note.** The figure shows only the upper pits in the dry valleys of the catchments.

5. Conclusions

The estimation of the sedimentation rates over two time intervals in the dry valley bottoms in the south of the forest zone (subzone of the southern taiga and the zone of the broad-leaf forests) and in the forest-steppe zone allows to speak about a significant decrease in the soil-erosion rates within the ploughed parts of the catchments over the last 30 years. The average rates of the soil material accumulation in the first-order valleys bottoms within all the catchments under study decreased at least 3–5 times. The main
reason for such significant reduction in the rates of the erosive degradation of the ploughed soils was a decrease in the surface runoff from the catchment slopes during the snowmelt period caused by the general climatic warming in the Russian Plain. The agricultural activity influence on the indicated sedimentation (erosion) dynamics within the catchments under study was apparently insignificant, possibly with the exception of the subzone of southern taiga (the coniferous and coniferous-deciduous forests).

Acknowledgments
The reported study was funded by the Russian Science Foundation according to the research project no. 15–17–20006.

References
[1] Porto P, Walling D E and Callegari G 2011 Hydrological Processes 25 886–900
[2] Golosov V N, Panin A V and Markelov M V 1999 Physics and Chemistry of the Earth, Part A: Solid Earth and Geodesy 24 881–885
[3] Parfitt R L, Baisden W T, Ross C W, Rosser B J, Schipper L A and Barry B 2013 New Zealand Geoderma 192 154–159
[4] Zapata F 2002 Handbook for the assessment of soil erosion and sedimentation using environmental radionuclides vol 219 (Springer)
[5] Golosov V N, Belyaev V R and Markelov M V 2013 Hydrological Processes 27 781–794
[6] Golosov V N, Ivanova N N, Gusarov A V and Sharifullin A G 2017 Eurasian Soil Science 10 1195–1208
[7] Zhang X and Walling D E 2005 Journal of Environmental Quality 34 514–523
[8] Silant’ev A N and Shkuratova I G 1983 Detecting Industrial Soil Contaminants and Atmospheric Fallout against the Global Contamination Background (Leningrad: Gidrometeoizdat)
[9] Almgren S and Isaksson M 2006 Journal of Environmental Radioactivity 91 90–102
[10] Karadeniz Ö, Çakir R and Karakurt H 2015 Journal of Environmental Radioactivity 146 27–34
[11] Ciszewski D, Czajka A and Blażej S 2008 Environmental Geology 55 1577–86
[12] Kirchner G, Strebl F, Bossew P, Ehlken S and Gerzabek M H 2009 Journal of Environmental Radioactivity 100 716–720
[13] Korobova E M, Dogadkin N N, Shiryayev A A, Kolotov V P, Kononkova N N and Turkov V A 2014 Journal of Geochemical Exploration 142 94–100
[14] Golosov V, Gusarov A, Litvin L, Yermolaev O, Chizhikova N, Safina G and Kiriukhina Z 2017 Proceedings of the International Association of Hydrological Sciences 375 23–27