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Metals in soils of erosional systems in forest zone in the central part of European Russia

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ABSTRACT

Small erosional landforms, despite their importance in mass transfer processes, have received insufficient attention in geochemical studies. This paper presents a case study dealing with geochemistry of two small erosional systems, typical of humid moraine landscapes of the central part of European Russia. They are considered as integrated systems comprising several units viz. slopes, bottoms, detrital fans as well as adjacent areas as sources of solid material. Chemical composition of topsoil (total concentrations of Ti, Zr, Mn, Co, Zn, Cu, Pb, Cr, V, Ni, Sn, Sr, Ba and concentrations of the acid-extractable Fe, Mn, Co, Zn, Cu, Pb, Cr, Ni) was used to explore the role of granulometry, pH, organic matter content and transport processes in geochemical differentiation of the systems. Spatial variations in granulometry across the various units indicate a progressive depletion of a finer material in the gully and comparatively invariant distribution of the same fractions within the balka. The granulometry is the main factor controlling the distribution of total and acid-extractable metal concentrations in both systems. The findings imply that the prevailing mechanism of metal migration through the studied systems is a suspension transfer in association with clay and silt particles. The young gully system operates as a transit system and shows higher geochemical differentiation than the aged balka system where some elements may accumulate in topsoil of the lower units of this system.

Introduction

In geochemical studies a lot of attention is paid to the behavior of trace elements in soils. Much research has been undertaken into mechanisms and controls of distribution and fractionation of potentially hazardous elements within various soil types. These studies have revealed the complicated nature of vertical redistribution of chemical elements during pedogenesis and have demonstrated the importance of environmental factors and soil-forming processes. Many studies reported on the significance of certain physical and chemical soil properties (such as organic matter content, granulometry, soil acidity) in retention and mobilization of different elements within soil profiles (Alloway, 1995; Gorbatov, 1988; Il'in and Syso, 2001; Kabata-Pendias and Pendias, 2001; Karpukchin, 1998; Ladonin, 2002; Nikonov et al., 1997; Samonova and Aseyeva, 2006; Vasil'evskaya and Shibaeva, 1991; Zyrin et al., 1979).

Understanding how trace elements vary at a landscape level is the subject of ecological studies in recent years. Following the development of the system approach in physical geography, spatial aspects of elements' behavior, for many years already, have been analyzed on the basis of catenary sequences. The catena, representing the simplest variant of cascading systems (Chorley and Kennedy, 1971), seems to be a useful object to study element migration and to determine typical geochemical patterns in soil cover of certain areas (Birkeland, 1999; Gennadiev and Kasimov, 2004). The spatial geochemical heterogeneity of catena sequences is a well-recognized phenomenon. The non-uniform nature of the elements' distributions is mostly explained as a response to a complex of environmental factors operating at various scales. The effects of lithologies, climatic conditions, water regime, slope gradients, land use and vegetation patterns, have all been cited as key factors responsible for geochemical heterogeneity of soils in various types of catena sequences (Rieuwerts et al., 2006; Samonova, 2002; Samonova and Aseyeva, 2013; Thanachit et al., 2006a, 2006b). Based on catena studies a number of methods were proposed to distinguish the patterns in elements' distributions, to isolate paragenetic groups of elements involved in migration and to assess the factors of geochemical changes along catenary sequences (Glazovskaya, 2002; Kasimov et al., 1995; Kosheleva et al., 2002; Thanachit et al., 2006a, 2006b).

At present, basin studies are attracting an increasing attention because of their significance for environmental planning and management both at a large (regional) and small catchment (local) scale. The implementation of the basin approach in geochemical studies faces many difficulties which arise mainly from methodological aspects. As a result, the behavior of elements in basin-type cascading systems such as river basins has been still poorly understood. It has been reported that gullies are local-scale cascading systems and important constituent parts of river basins in terms of migration processes and sediment delivery to river valleys (Golosov, 2006) or to reservoirs (Valentin et al., 2005). They are very common features of a present-day landscape and

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not only occur in marl lithologies of mountainous or hilly regions but according to Valentin et al. (2005) also more extensively in areas with soils on loess or loess-like deposits in Europe, China, North America and in sandy regions such as the Sahelian zone and north-east Thailand. Being depressions in the relief gullies are common locations for illegal dumping of hazardous substances, which may be mobilized, retained or recycled during the transport. To our knowledge only limited research has touched upon this subject. In most studies, tracers (such as carbon, nitrogen, radionuclide ^{137}Cs, magnetic particles or the strontium isotope ratio) are used to fingerprint a sediment (Gennadiev et al., 2008; Valentin et al., 2005), however, there is a particular lack of information on the concentration, distribution and behavior of potentially hazardous trace elements. Characterization of spatial variability and distribution of elements seem to be critical to accurate prediction of geochemical processes taking part at the scale of the river basin, in which gullies play an important role with respect to sediment delivery. For the present geochemical study, two erosional landforms in the central part of European Russia were selected as model examples. They are located in the area with a 30-year history of integrated environmental research, including detailed studies on geology, geomorphology, soil cover and vegetation (Antonov et al., 2001; Gerasimova and Isachenkova, 2003). Gullies and dry valleys are common relief features and their morphology and genesis have been thoroughly studied (Belyaev et al., 2005a; Golosov, 2006; Panin et al., 2009). The present paper deals with the geochemistry of these landforms. It describes the spatial distributions of total and acid-extractable metal concentrations across their major structure units (adjacent catchment areas, slopes, bottom, fan) and explores the role of granulometry, pH, organic matter content and transport processes.

Materials and methods

Study area

The study area is located around the Satino Experimental Station of Moscow State University (Fig. 1), 100 km to the southwest from Moscow in the Smolensko-Moskovskaya Upland (314 m asl). The climate is humid temperate continental, characterized by moderately moist and warm summers ($T_{July} = 17.5$ °C) and cold winters (mean $T_{January} = -9.9$ °C), and a mean annual precipitation of about 600 mm. Two-third of the annual precipitation falls during the warm period of the year.

The present-day morphology of the study area is represented by glacial relief on the interfluves dated to Moscow (MIS 6) glaciations, corresponding to Saal III stage of Saal glaciation in West European glacial regions (Velichko et al., 2011), interchanging with the post-Moscow fluvial relief of river valleys and gullies. The major rivers of the study area are the Protva River (average annual discharge 9.9 m^3/s) and its tributary—the Isma (Fig. 1). The highest discharge occurs during spring floods due to significant snowmelt, however in gullies and small valleys

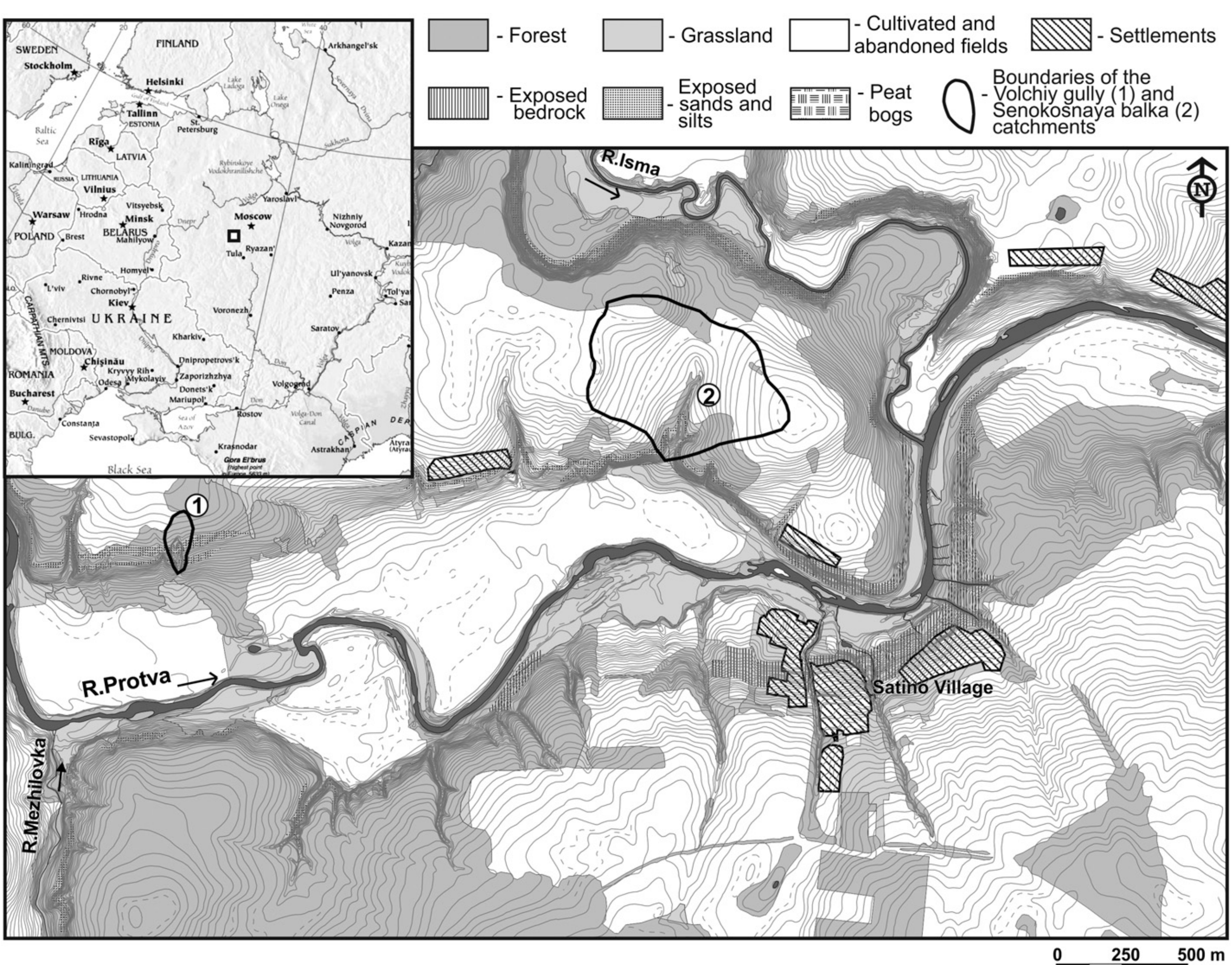

Fig. 1. Physiographic map of the study area (modified after Panin et al., 2009) with locations of the study objects 1 and 2. Contour lines are drawn at 1 m interval.