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# Impact of former uranium mining activities on the floodplains of the Mulde River, Saxony, Germany

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ABSTRACT

The Mulde River drains the former uranium mining areas in Saxony (Germany), which has led to a large-scale contamination of the river and the adjacent floodplain soils with radionuclides of the uranium decay series. The objective of the investigation is to quantify the long-term effect of former uranium mining activities on a river system. All of the investigated environmental compartments (water, sediment, soil) still reveal an impact from the former uranium mining and milling activities. The contamination of water has decreased considerably during the last 20 years due to the operation of water treatment facilities. The uranium content of the sediments decreased as well (on average by a factor of 5.6), most likely caused by displacement of contaminated material during flood events. Currently, the impact of the mining activities is most obvious in soils. For some of the plots activity concentrations of >200 Bq/kg of soil were detected for uranium-238. Alluvial soils used as grassland were found to be contaminated to a higher degree than those used as cropland.



## 1. Introduction

The former German Democratic Republic (GDR) was one of the largest producers of uranium in the world and the most important uranium supplier of the USSR. The main mining areas were located in the western part of the Saxon Ore Mountains (German: Erzgebirge) and its foreland in Thuringia. The former uranium mining areas in Saxony are drained by the Mulde River, which has led to a large-scale contamination of the river and the adjacent floodplain soils with radionuclides of the uranium decay series (SSK, 1991; Beuge et al., 1999; Mann, 2012). After the German reunification in 1990 uranium mining was stopped. Since 1991, the former uranium mining areas are subject to a huge remediation project (Mann, 2012; Wismut, 2013). The total amount of radionuclides discharged during uranium mining activities is unknown. However, quantification of the extent of the contamination is subject of current investigations by the 'Wismut GmbH'. First results indicate that during the period from 1979 to 2008 an amount of 233 (metric) tons of uranium (equivalent to 5884 GBq uranium of natural isotopic composition), and 103 GBq of radium-226 must have been discharged by waste water into the Mulde River. For the period from 1979 to 2012, a discharge of 241 (metric) tons of uranium (equivalent to 6091 GBq), and 105 GBq of radium-226 was estimated. Roughly the same amount of radionuclides were discharged into the Weiße Elster River, which drains the former uranium mining area in Thuringia (Schmidt, 2013). There are several sources of contamination, whose relative importance vary with space and time. Most important contamination paths during the active mining period were mine water and water from mining dumps of waste rock, low-grade ore, and tailings (residues of uranium ore processing). The same holds true for current conditions. Today, those waters are treated by water treatment plants (WTP). But as a result of their continuous discharges this is still one of the most important contamination paths. Furthermore, processing waters from uranium mining and ore processing activities were contamination paths in the active period. Today, remediation activities produce contaminated processing waters. On a smaller scale, airborne contamination paths existed resulting from radon or dust produced by dry tailing ponds, uranium mining, and ore processing in the past. Today, dust is released during remediation activities.

The Mulde River System consists of three main rivers: Zwickauer Mulde, Freiberger Mulde and Vereinigte Mulde (see Fig. 1). The Zwickauer Mulde River has its source in the western Ore Mountains and passes the cities of Aue and Bad Schlema, which are located in

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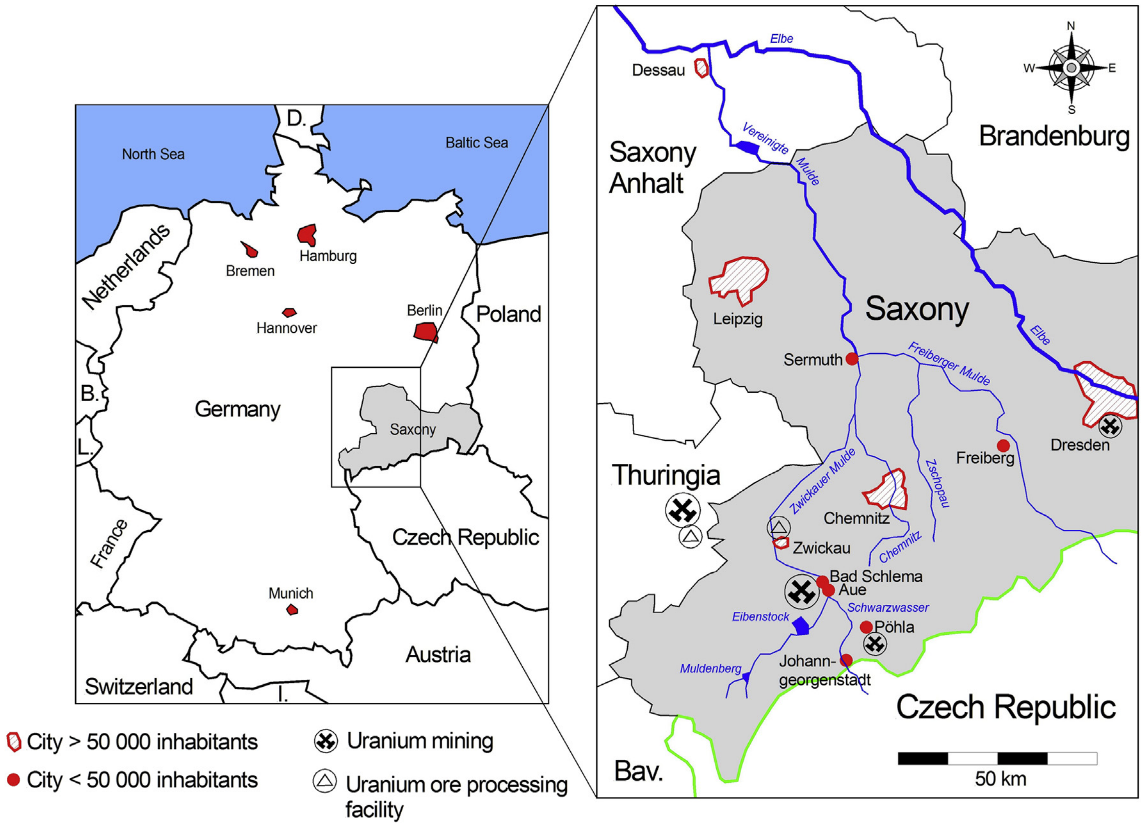


**Fig. 1.** Map of the Mulde River system with important locations of uranium mining. Abbreviations: D. = Denmark, B. = Belgium, L. = Luxembourg, I. = Italy, Bav. = Bavaria.

the most important uranium mining area of Saxony. Moreover, the Schwarzwasser River, which is a tributary of the Mulde River draining the uranium mining areas of Johanngeorgenstadt and Pöhla, merges with the Zwickauer Mulde River, and downriver from the Ore Mountains the Zwickauer Mulde River passes the former uranium ore processing facility near Zwickau/Crossen.

The Freiberger Mulde River originates in the eastern part of the Ore Mountains. It also drains important mining areas, but, in contrast to the Zwickauer Mulde River, there were no uranium mining activities in the catchment of the Freiberger Mulde River. The confluence of the two rivers is located close to the village of Sermuth, where they merge to form the Vereinigte Mulde River, which flows into the Elbe River north of the city of Dessau.

In the present study we aimed on quantifying long-term effects of the former uranium mining and milling activities in Saxony (Germany). Radionuclide content in different environmental compartments (water, sediment, soil) of the Mulde River system, including uranium and its decay products radium-226, lead-210, and polonium-210, were determined (Bister, 2012; Riebe and Bister, 2012). Focusing on contamination levels in floodplain areas used as farmland, and considering the temporal evolution of the contamination, we demonstrated that all of the compartments still reveal an impact of the former uranium mining and milling activities, which is decreasing slowly. The assessment of potential radiation exposure of man resulting from agricultural use of contaminated floodplain soils is still in progress and will be published separately.

## 2. Materials and methods

The Vereinigte Mulde River ranks fourth among the largest tributaries of the Elbe River with a mean discharge of 75 $m^3$/s. However, the discharge fluctuates in a wide range. For example, between 1961 and 1990 the Bad Düben water gauge showed a mean discharge of 63.8 $m^3$/s, fluctuating between 14.6 $m^3$/s and 472 $m^3$/s as a minimum and a maximum value, respectively. The Zwickauer Mulde River and Freiberger Mulde River have mean discharges of 28.8 $m^3$/s and of 35.2 $m^3$/s at their confluence near the village of Sermuth, respectively (Beuge et al., 1999).

To ensure comparability, sampling sites had to fulfill certain requirements. Thus, only areas of more than one hectare in floodplains under agricultural use were sampled, which are frequently inundated to a depth of 0.5 and 2 m (Bister, 2012; Riebe and Bister, 2012).

A total of 26 water samples, 38 sediment samples, 52 pooled soil samples, and samples from 9 soil profiles were collected. A map showing all sampling locations is given in the Supplemental Information (Fig. A1). Water and sediment were sampled in April, May, and October 2008. Soil samples were collected between June and October 2008. Except for a few cases, in which modification of the standard procedure was necessary, sampling was consistent with the measurement guidelines for monitoring of environmental radioactivity and radioactive emissions from nuclear facilities of the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU, 2006). The calculation of measurement uncertainties was performed according to the ‘Guide to the Expression of Uncertainty in Measurement’ (GUM, 1995). Quality of analyses was maintained by participating in International Atomic Energy Agency (IAEA) proficiency tests (IAEA-CU-2008-03, IAEA-CU-2009-03, IAEA-CU-2010-03), and by using reference samples (well-characterized material from former projects with comparable matrix, and samples from a French Alternative Energies and Atomic Energy Commission (Commissariat à l'énergie atomique et aux énergies alternatives, CEA) proficiency test performed in 2007: ‘Polonium 210 and Lead 210 in water samples’). All chemicals used