A predictive assessment of the uranium ore tailings impact on surface water contamination: Case study of the city of Kamianske, Ukraine

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Abstract

In this study, we present an assessment of the uranium ore tailings impact on groundwater and surface water contamination. The radioactive materials were deposited in the tailings storage facility "Dniprovske" (the city of Kamianske, Ukraine) from 1954 to 1968; now it contains about $5.85 \cdot 10^6$ m^3 of hazardous waste on the area of about 76 ha in the floodplain of the Dnipro river. The lack of a proper waterproof screen below deposited tailings and in the earthen dam led to permanent watering of radioactive materials, their leaching and migration in groundwater into the nearest small Konoplianka river. We used the reports on previous site-specific studies conducted in 1999–2016, monitoring results, and the field studies conducted in 2022 with the authors' team participation. The calculations performed with the advection-dispersion model to simulate transport of radionuclides ^{238}U, ^{230}Th, ^{226}Ra and ^{210}Pb through the embankment to the Konoplianka river and dilution relations were compared to the monitoring data of the surface water quality. Among four radionuclides, uranium poses the greatest risks today; the subsurface runoff increases its concentration in the Konoplianka river water by several times over the background value. It is estimated that due to much more intensive sorption in the shallow aquifer, the contribution of ^{226}Ra and ^{210}Pb to the increase in radioactivity of Konoplianka river water is insignificant compared to uranium, whereas the migration front of ^{230}Th has probably not yet reached the riverbank. In the next 50 years the radionuclide fluxes will increase by 1.3–3.7

times for different isotopes, with the uranium subsurface runoff growing at a slower rate than nowadays. These results are of high significance for improving hydrological, hydrogeological, and geotechnical monitoring on this hazardous facility to maintain its radiation safety.

Introduction

The development of nuclear energy and related economy sectors results in the extensive accumulation of radioactive tailings materials that pose significant risks to the environment and humans (Brunnengräber et al., 2018). Awareness of the significant hazards caused by environmental contamination encourages searching for new strategies to maintain the safety of such facilities (Kördel et al., 2013) by improving the radioactive waste management that continues to be a challenging issue (Landa, 2004). Large tailing storage facilities in many countries continue to be dangerous, especially those created in 1960–1980 without properly addressing the environmental risks and following strict safety requirements.

Good practices in research and monitoring, including observations, closure, and reclamation of abandoned tailings were demonstrated in the European countries (Gao et al., 2003; Naamoun and Merkel, 2008; Carvalho, 2014; Stsiapanau, 2022), the USA (Bradley, 1992; Rima, 2012), and Australia (Lottermoser, 2006). Alongside this, some former USSR countries, including Ukraine, have numerous uranium legacy sites (Smith et al., 2003; Mirsaidov et al., 2010; Korovin et al., 2001) which still need proper reclamation to ensure the radiation safety through long-term isolation of low-level radioactive waste from aquifers and surface water bodies.

Clear examples of such hazardous sites are numerous radioactive sludge storages and tailings in the densely populated central part of Ukraine, which were created due to high demand on uranium for military purposes during the Cold War without proper understanding of radiation hazard. Most of such facilities were constructed by filling ravines through blocking them by earthen dams. Insufficient waterproof screens (if they existed) have degraded since that time that enhanced migration of radionuclides from tailings into underlying soils, groundwater, and surface watercourses.

Fortunately, almost all tailings were covered by a mineral or soil protective layer to prevent wind erosion of the waste body, and emission of radioactive gases, and to minimize gamma radiation into the atmosphere. Creating and maintaining a reliable lining or waterproof screen in the basement and the dam body is the much more challenging task, because infiltration leads to leaching of hazardous substances followed by groundwater contamination. In the most cases, it is quite difficult to identify visually the areas of enhanced migration in the dam, and especially, the waste layer. In this context, it is worth mentioning that geophysical methods were found to be a promising tool for contouring the zones of enhanced infiltration (Orlinska et al., 2022). Along with geophysical studies, investigating the mechanisms and patterns of radionuclide migration by other methods (Kersting et al., 1999; Huang et al., 2022) create the theoretical basis for reliable prediction and elaboration of proper organizational and engineering solutions to minimize the negative impact of tailing storage facilities on the water quality.

The experience of such facility operation shows that basically the protective cover layer performs its intended purpose. However, due to high water permeability and the absence of proper capturing of surface runoff the waste body remains permanently watered that facilitates leaching of radionuclides. As a result, leakage zones evolved in earthen dams over several decades are sometimes manifested visually, more often in geophysical fields (Pikarenia et al., 2012, 2013), especially in the case of missing or poor waterproof screens. Assessment of radionuclide migration into shallow aquifers and surface water bodies, evaluation of the rate and scale of radioactive contamination is based not only on field studies but also on mathematical modelling (Ziemińska-Stolarska et al., 2012; Medved' and Cerný, 2019), particularly, with using artificial neural networks (Dragović, 2022). These models enable prediction of transport pathways of leaching products to aquifers (Rauert et al., 1993; Magasheva and Yakunin, 2003; Dewiere et al., 2004) and surface water bodies (Monte, 1995; Liu et al., 2015; Rumynin, 2015).

After the Chernobyl accident, the monitoring and control of radioactive contamination remains topical in Ukraine because of the urgent creation of many temporary near-surface radioactive storages in the Prypiat basin after 1986. This increased the need to ensure the environmental safety and protect human health (Berkovski et al., 1996; Voitsekhovitch et al., 2006; Krylov et al., 2020). The load of such storages leads to the developing degradation of aquatic ecosystems that becomes threatening to the environmental sustainability of small river basins (Andrieiev et al., 2022; Hapich et al., 2022a), which feed large watercourses transporting simultaneously various contaminants.

The risk imposed by existing radioactive tailings to the environment and humans is exacerbated by the discrepancy between stronger modern requirements to the design and construction of such facilities and outdated engineering solutions applied during their construction and commissioning. The most problematic issue is the lack of proper waterproof screens at the basement of the tailing impoundment and the earthen embankment. The improper location of tailings had also a negative impact because such facilities were often placed following the purposes of production rather than the environmental safety requirements. Hence, a lot of tailings storage facilities were constructed in river floodplains and within residential areas.

Partial declassification of data related to the operation of radioactive waste storages over the past decades facilitated the access to investigation of such facilities, evaluation of their hazard and environmental impact (Tkachenko et al., 2020; Bugai et al., 2022), with applying mathematical modelling of radioactive groundwater contamination for the specific sites (Bugai et al., 2018). However, the quantity and quality of data and information on radioactive contamination caused by tailings sites in Ukraine still remains insufficient for comprehensive understanding of the scale of environmental threats. Thus, more studies are needed to justify monitoring and reclamation strategy for all abandoned and most hazardous tailings. These studies should combine mathematical modelling with systematic monitoring focused on groundwater-surface water interaction in order to predict and control evolving radionuclide migration.

Therefore, the aim of this paper is to make the site-specific predictive assessment of long-term groundwater and river contamination by the uranium chain elements. The study focuses on one of the most hazardous uranium ore tailings in Ukraine located in the city of Kamianske (formerly Dneprodzerzhinsk). The potential long-term adverse effect of this facility on water quality in the Dnipro river makes this study incredibly important for water supply in numerous cities and settlements downstream.

Section snippets

Materials and methods

As the data sources we used the technical reports on the status and environmental impact assessment conducted by Ukrainian competent institutions in 1999–2016 under the supervision of S.G. Izmailov, D.P. Khrushchev, O.V. Voitsehovich, G.V. Lysychenko, O.S. Skalskyi and other experts within the state and regional programmes including those approved by the Cabinet of Ministers. These institutions are Ukrainian Hydrometeorological Institute of the State Service of Emergencies and National Academy

Results and discussion

The assessment of radionuclide transport in groundwater to surface watercourses included the calculation of 1) radionuclide concentrations on the shallow aquifer boundary that is the contour of discharge to the Konoplianka river, 2) radionuclide fluxes to the Konoplianka and Dnipro rivers, and 3) the concentrations in these watercourses. Half-life of radionuclides were given according to (IAEA, 2022).

The results in Fig. 5 were obtained for the present time (2023) and the end of the coming

Conclusions

- 1.
  In this study, we assessed the uranium ore tailings impact on groundwater and surface water contamination induced by the tailings storage facility “Dniprovske” (“D”) located in the city of Kamianske, Ukraine in the floodplain of the Dnipro river. The importance of this site lies in its potential long-term negative influence on water quality in the Dnipro river. The monitoring data evidenced the migration of radionuclides in groundwater to the small Konoplianka river upstream of its confluence

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References (57)

- P. Bauer *et al.*

  Transport of a decay chain in homogenous porous media: analytical solutions
  J. Contam. Hydrol.
  (2001)
- F.P. Carvalho

  The national radioactivity monitoring program for the regions of uranium mines and uranium legacy sites in Portugal
  Procedia Earth and Planetary Science
  (2014)
- J. Cetnar

  General solution of Bateman equations for nuclear transmutations
  Ann. Nucl. Energy
  (2006)
- L. Dewiere *et al.*

  90Sr migration to the geo-sphere from a waste burial in the Chernobyl Exclusion Zone
  J. Environ. Radioact.
  (2004)
- S. Dragović

  Artificial neural network modelling in environmental radioactivity studies – a review
  Sci. Total Environ.
  (2022)
- E.R. Landa

  Uranium mill tailings: nuclear waste and natural laboratory for geochemical and radioecological investigations
  J. Environ. Radioact.
  (2004)
- T. Lavrova *et al.*

  Radioecological assessment and remediation planning at the former uranium milling facilities at the Pridnieprovsky Chemical Plant in Ukraine
  J. Environ. Radioact.

(2013)

- I. Medved' *et al.*

  Modeling of radionuclide transport in porous media: a review of recent studies
  J. Nucl. Mater.
  (2019)
- L. Monte

  Evaluation of radionuclide transfer functions from drainage basins of fresh water systems
  J. Environ. Radioact.
  (1995)
- W. Rauert *et al.*

  Isotope-hydrogeological case study on the penetration of pollution into the deep tertiary aquifer in the area of Munich, Germany
  J. Contam. Hydrol.
  (1993)