

## POTENCIJALNO TOKSIČNI ELEMENTI U PODZEMNIM VODAMA RUDNIKA BAKRA: ZASTUPLJENOST, NIVOI ZAGAĐENJA I PROCENA RIZIKA PO ZDRAVLJE

### POTENTIALLY TOXIC ELEMENTS IN GROUNDWATER OF A COPPER MINING AREA: OCCURRENCE, POLLUTION LEVELS, AND HEALTH RISK ASSESSMENT

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*U ovom radu ispitano je zagađenje podzemnih voda potencijalno toksičnim elementima u rudarskom regionu u Majdanpeku (Srbija). Podzemne vode su analizirane na deset potencijalno toksičnih elemenata, uključujući As, Cu, Cr, Pb, Cd, Co, Ni, Zn, Hg i Mn. Nivoi zagađenja su ispitani korišćenjem indeksa zagađenja (PI), Nemerovog indeksa (NI) i indeksa zagađenja teškim metalima (HPI), dok su nekancerogeni i kancerogeni zdravstveni rizici procenjeni korišćenjem indeksa HI i ILCR. Povišeni nivoi bakra (Cu), arsena (As), kadmijuma (Cd) i olova (Pb) identifikovani su u uzorcima podzemnih voda. Rezultati su pokazali da su podzemne vode na istraženom području umereno do jako zagađene. Rezultati procene zdravstvenih rizika pokazali su da doprinos različitim potencijalno toksičnih elemenata nekancerogenom riziku opada u sledećem redosledu  $As > Cu > Cr > Pb > Cd > Co > Ni > Zn > Hg > Mn$ , kako kod odraslih tako i kod dece. Deca su bila podložnija nekancerogenom riziku od odraslih, pri čemu je srednja vrednost HI bila gotovo 2 puta veća nego kod odraslih. Najveći doprinos kancerogenom riziku za obe populacione grupe pokazao je As, zatim Cd, Cr i Pb. Što se tiče odraslih, svi uzorci imali su vrednost ILCR veću od dozvoljene granice od  $1.0 \times 10^{-4}$ . Međutim, deca su manje podložna kancerogenom riziku, pri čemu je 66.7% uzoraka premašilo dozvoljenu granicu. Ovi rezultati naglašavaju hitnu potrebu za intenzivnijim praćenjem podzemnih voda i razvojem sveobuhvatnih strategija za remedijaciju u rudarskom regionu Majdanpeka.*

**Ključne reči:** zagađenje podzemnih voda; potencijalno toksični elementi; nekancerogeni rizik; kancerogeni rizik

*In this paper, groundwater contamination with potentially toxic elements (PTEs) was investigated within the Majdanpek copper mining region in Serbia. Groundwater was analyzed for ten PTEs, including As, Cu, Cr, Pb, Cd, Co, Ni, Zn, Hg, and Mn. Pollution levels were examined using pollution index (PI), Nemerow index (NI), and heavy metal pollution index (HPI), while non-carcinogenic and carcinogenic health risks were assessed using hazard index (HI) and incremental lifetime cancer risk (ILCR). Elevated levels of copper (Cu), arsenic (As), cadmium (Cd), and lead (Pb) were identified in groundwater samples. The results also showed that groundwater in the study*

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area is light to heavy polluted. The health risk assessment results revealed that contribution of different PTEs to non-carcinogenic risk decrease in the order of As > Cu > Cr > Pb > Cd > Co > Ni > Zn > Hg > Mn, for both adults and children. Children were more prone to non-carcinogenic risk than adults, with the mean HI value almost 2 times higher than the adults. The greatest contributor to carcinogenic risk for both population groups was As, followed by Cd, Cr, and Pb. With regard to adults, all of the samples had ILCR value greater than the allowable limit of  $1.0 \times 10^{-4}$ . However, children were less susceptible to carcinogenic risk, with 66.7% of samples exceeding the allowable limit. These findings emphasize the urgent need for intensified groundwater monitoring and the development of comprehensive remediation strategies in Majdanpek mining region of Serbia.

**Key words:** groundwater pollution; potentially toxic elements; non-carcinogenic risk; carcinogenic risk