ENVIRONMENTAL ASSESSMENT OF POTENTIALLY TOXIC ELEMENTS AND ASSOCIATED EXPOSURE AND RISK IN DISTRICT SWABI, KHYBER PAKHTUNKHWA, PAKISTAN

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Abstract

This study offers a detailed analysis of the physicochemical properties and potentially toxic elements (PTEs) in groundwater, surface water, soil, and sediment from District Swabi KP, Pakistan. A total of 244 samples including 126 groundwater, 18 surface water, and 100 soil/sediment samples were collected from dug wells, tube wells, springs, rivers, agricultural fields, and foothill zone. The concentrations of PTEs were analyzed using DR2800 spectrophotometry and atomic absorption spectroscopy (AAS Analyst 700), and compared with WHO and USEPA standards. Results showed that 52.4% of groundwater and 44.5% of surface water samples exceeded the WHO pH guideline (>8.5). Fluoride levels reached up to 14.2 mg/L, with 78.6% of groundwater samples exceeding safe limits. Elevated concentrations of NO_3^-, NO_2^-, and SO_4^{2-} indicated contamination from agricultural, industrial, and geogenic sources. Surface water contained higher levels of Cu, Cd, Ni, Pb, Hg, Na, and Mn, while Cr, Ca, and Fe were more abundant in groundwater. Cd, Pb, Ni, and K frequently exceeded WHO limits, posing public health risks. Health risk assessment based on average daily dose (ADD) and hazard quotient (HQ) revealed that As, Co, and Cd levels in drinking water exceeded safe thresholds (HQ > 1), indicating

non-carcinogenic risks. Fluoride exposure affected 68.1% of adults and 67.4% of children, with children more vulnerable due to higher relative intake. Arsenic exceeded WHO limits (10 μg/L) in 63% of groundwater samples, with all calculated cancer risk (CR) values surpassing the US EPA threshold (10^{-6}), indicating elevated carcinogenic risk. Soil and sediment analysis revealed elevated Ni, Fe, and Cd levels. Contamination and enrichment factors suggested both geogenic and anthropogenic sources. The geo-accumulation index (Igeo) and potential ecological risk index (PERI) indicated moderate ecological risks, especially from Hg and Cd. Total hazard index (THI) and total carcinogenic risk index (TCRI) highlighted that children face greater risks, primarily through oral ingestion. Multivariate analyses (PCA-MLR) identified five contamination sources: (a) geogenic processes, (b) mixed geogenic-anthropogenic inputs, (c) geochemical processes, (d) agricultural pollution, and (e) industrial effluents contributing to fluoride contamination. Spatial mapping revealed higher contamination in northern regions and decreasing levels toward the south and southeast.

The findings highlight the urgent need for groundwater monitoring, pollution control, and public health interventions to address ecological and health risks in the region.