

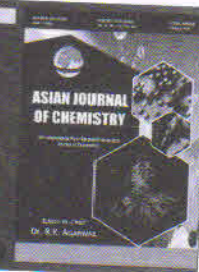


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Groundwater Fluoride Contamination in Balochistan, Pakistan: Health Risk and Regional Variability Analysis using HQ and NPI Indices

GHULAM MURTAZA ARAIN^{1,*}, NAZIA SATTAR¹, SUMAIRA KHATOON², SADAF NASEEM³ and SHAKEEL BADSHAH⁴

¹Pakistan Council of Research in Water Resources, Main University Road, Karachi, Pakistan

²Centre of Excellence in Marine Biology, University of Karachi, Karachi, Pakistan

³Department of Geology, University of Karachi, Karachi, Pakistan

⁴Pakistan Council of Research in Water Resources, Islamabad, Pakistan

*Corresponding author: E-mail: drmurtaza1977@gmail.com

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Groundwater fluoride contamination in Balochistan, Pakistan, poses significant public health and socio-economic challenges. This study comprehensively assessed groundwater quality across 7 districts, including Quetta, Loralai, Sibi, Kachi Bolan, Sohbatpur, Jafarabad and Naseerabad, through 825 samples collected during 2022 and 2023. Parameters analyzed included fluoride (F^-), total dissolved solids (TDS), electrical conductivity (EC) and pH. Advanced indices, including hazard quotient (HQ), fluoride concentration (C_f), pollution index (PI) and Nemerow Pollution Index (NPI), were used to evaluate risks for male and female population groups. The highest F^- contamination was observed in Sibi (58% unsafe samples), followed by Loralai (20.2%), with contamination severity ranked as Sibi > Loralai > Sohbatpur > Kachi Bolan > Quetta > Jafarabad > Naseerabad. HQ analysis revealed children are significantly more vulnerable, with the highest HQ for children observed in Sohbatpur (mean: 1.128). The C_f analysis showed minimal risk for infants (< 1 year) but higher exposure for children (1-8 years), particularly in Sibi (mean: 0.112 mg/L). The NPI findings classified Naseerabad as minimal risk (NPI: 0.859), while Sibi, Sohbatpur, Kachi Bolan and Loralai posed high risks (NPI: 1.33-1.50), whereas EC and TDS variability highlighted groundwater quality differences, with high salinity and TDS concentrations in Sohbatpur and Jafarabad indicating unsuitability for drinking.

Keywords: Groundwater, Toxicity, Hazard quotient, Nemerow Pollution Index, Children's vulnerability, Balochistan, Pakistan