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Unusually High Levels of Fluoride and Nitrate in Groundwater in Southern India: Water Quality Indices and Associated Health Hazard Implications

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Abstract

Groundwater is crucial for supporting the global population, with water quality having a significant impact on human health. In this study, we examined the groundwater geochemistry, health risks, and water quality index associated with consuming water contaminated by high levels of fluoride and nitrate in and around Gokak, Belgaum district, Karnataka. Fifty (50) groundwater samples were collected, and thirteen (13) physicochemical parameters were analysed following APHA methods. Results indicates that levels of pH, EC, TDS, fluoride, nitrate, and chloride exceed the WHO recommended standards. Fluoride concentrations range from 0.05 mg/L to 6.5 mg/L, while nitrate concentrations range from 2.66 mg/L to 118.8 mg/L. Excessive fluoride levels were observed in 14% of samples, and nitrate levels exceeded limits in 26%. Through Principal Component Analysis (PCA), four components explained 82.70% of the dataset variance. The water quality index (WQI) results categorize 26% of samples as excellent, 44% as good, 14% as poor, and 16% as unsuitable for any purpose, with 30% of samples overall being unfit for drinking. Health risk assessments for fluoride and nitrate indicate that 68% of samples had a hazard index (HI) value >1, highlighting a considerable health risk associated with groundwater consumption, particularly for women. Our findings suggest that both natural and human activities contribute to groundwater contamination. To further delineate pollution sources, stable isotopic studies are recommended.

Keywords: Fluoride, Nitrate, Health, Karnataka, South India

Introduction

Groundwater is a vital global resource, supplying nearly half the world's population with drinking water (Anisha *et al*., 2025). In India, it provides 60–85% of rural drinking water (Tanwar *et al*., 2023). Its quality is influenced by both geogenic (water–rock interaction) and anthropogenic factors (fertilizers, waste, industrial effluents) (Sinha *et al*., 2023). Over extraction, driven by population and industrial growth, threatens sustainability (Tanwar *et al*., 2023), and contaminated groundwater poses serious health risks (Sinha *et al.,* 2023). Fluoride (F^-) and nitrate (NO_3^-) are prominent contaminants in groundwater (Egbueri *et al*., 2023). While fluoride supports bone and dental health, excess levels cause fluorosis and other health issues (Dubey *et al.,* 2021). Its sources include geogenic inputs and phosphate fertilizers (Subba Rao, 2018). Elevated nitrate levels, largely from fertilizers, poor waste management, and runoff, are also a concern (Dai *et al.,* 2024). Nitrate exposure is linked to methemoglobinemia, thyroid disorders, and cancer (Subba Rao, 2018). Statistical tools like correlation analysis and PCA help reveal relationships between water quality parameters and underlying factors (Gaikwad *et al.,* 2020). Various indices such as HQ, HI, and WQI offer integrated assessments of water quality and related health risks (Patil *et al.,* 2024).

Following a recent study in southern Karnataka (Thabrez and Parimalarenganayaki, 2024), this research focuses on groundwater in the Gokak region, northern Karnataka. It aims to: 1) assess spatial variation and health risks of fluoride and nitrate using HQ and HI; 2) evaluate groundwater quality using WQI; and 3) identify factors influencing groundwater chemistry through PCA and correlation analysis.

Materials and Methods

Study Area

The study area (Fig.1) lies on the eastern edge of the Western Ghats (74°35'59" E - 75°19'59" E, 15°40'N - 16°25'N, ~4,146.40 km^2) with undulating terrain. It is a part of the Ghataprabha (Krishna tributary) basin, with a dendritic to sub-

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