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MULTIVARIATE ANALYSIS ON HYDROGEOCHEMICAL EVOLUTION OF GROUNDWATER IN A GEOLOGICALLY CONTROLLED AQUIFER SYSTEM

S.H.U. Hansani[1]*, R. Weerasooriya[1] and P.L. Dharmapriya[2]

[1]*Centre for Water Quality Research, National Institute of Fundamental Studies, Kandy, Sri Lanka.*
[2]*Department of Geology, University of Peradeniya, Peradeniya, Sri Lanka.*
*uthpala.he@nifs.ac.lk

This study investigated hydrogeochemical evolution in the Netiyagama area, located in the North Central Province of Sri Lanka. A total of 120 water samples were analysed alongside silicate rock analysis to characterise water-rock interactions. Mineralogical studies and principal component analysis identified 16 ions (Na^+, K^+, Ca^{2+}, Mg^{2+}, $Cl^–$, $SO_4^{2–}$, $HCO_3^–$, $CO_3^{2–}$, Si^{4+}, Sr^{2+}, Fe^{3+}, Mn^{2+}, Al^{3+}, Zn^{2+}, Cu^{2+}, Co^{2+}) that would contribute to groundwater chemistry. They were used in a hierarchical cluster analysis (HCA) to identify water clusters linked to geological conditions of the area dominated by granitic gneiss, hornblende biotite gneiss and charnockitic gneiss. The HCA delineated 7 clusters, which revealed distinct chemical signatures correlated with lithological heterogeneity and spatial distribution of fractures. The hydrogeochemical evolutionary trends indicate a progression of water chemistry. Initially reverse ion exchange dominates in recharge zones, where Na^+ substitutes for Ca^{2+} and Mg^{2+} in aquifer materials, resulting in water enriched with Ca^{2+} and Mg^{2+} ions as indicated by negative chloro-alkaline indices and elevated Ca^{2+}/Na^+ ratios (~1.7). The recharge zone groundwater between major fold axes exemplifies this stage of evolution, characterised by mixed $CaNaHCO_3$ water exhibiting minimal chemical variability, indicative of fresh recharge water. As groundwater moves towards discharge areas, prolonged residence time and interaction with diverse lithologies lead to the depletion of exchangeable sodium with the aquifer materials. Additional processes, such as the dissolution of secondary calcite, release Ca^{2+} and $HCO_3^–$ ions, prompting a shift toward normal ion exchange, where Ca^{2+} and Mg^{2+} are exchanged for Na^+, or mixed ion exchange environments, as indicated by variations in Ca/Na ratios (0.5 – 1.0). These geochemical transformations coincide with an increase in mineralisation parameters such as salinity, nitrate concentration, and the presence of heavy metals, particularly under anthropogenic influences (*e.g.* fertilisers) in the most evolved groundwater clusters. The clustering results highlight a distinct shift from bicarbonate-rich recharge waters to chloride-dominated discharge waters, reflecting increased water-rock interactions. The findings reveal critical aquifer geochemical processes, vital for sustainable groundwater management in geologically complex areas.

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Keywords: Multivariate analysis, Equilibrium reactions, Groundwater evolution, Dry zone