Hydrogeochemical characterization to understand water resources availability in the Nanmoku watershed, Central Japan
水資源利用可能性の評価を目的とした群馬県南牧川流域の水文地球化学的特徴の評価

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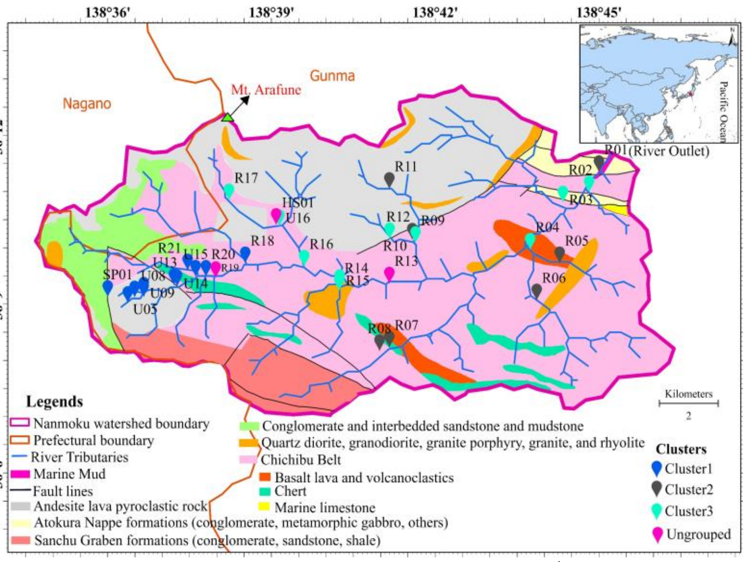
1. Introduction

The strategic utilization of water resources offers the opportunity to strengthen rural communities and promote sustainable development. In developed nations like Japan, depopulation and aging in rural areas over the recent decade have led to the deterioration of agricultural production and infrastructure, necessitating heightened investigation into stable water resources for agricultural irrigation and renewable energy production.

Nanmoku village settled amidst cedar and deciduous forests along the Nanmoku River (with tributaries winding through the surrounding mountains) grapples with substantial aging (67.5%) and depopulation issues. The smart utilization (e.g. hydropower production) and conservation of the Nanmoku River and its associated springs are crucial to addressing the challenges (e.g., agricultural productivity decline) stemming from the demographic shift. So, understanding hydrogeochemistry and water availability is essential for the village which has limited information on the subject. Therefore, this research aims to understand water resource availability using hydrogeochemical indicators to propose effective improvement measures.

2. Study area and methods

The Nanmoku watershed in Central Japan spans 129.13 km^2 and includes Nanmoku village with 1,512 residents. Its elevations range from 275 m to 1,454 m, averaging 12.3°C in temperature and 1299.9 mm in rainfall (as per nearby Nishinomaki station). Geologically, it features andesite lava pyroclastic rock in the north and pebbly mudstone with chert, limestone, and basalt in the south (the data above are from the Japan Meteorological Agency and official website of Nanmoku Village).



Source: (Yamazaki, 2019; GSJ Accessed 3rd March 2024)

Fig. 1 Nanmoku watershed, Gunma Prefecture, Central Japan.

2.1 Sample collection and analysis

A total of 31 and 23 water samples from dispersed locations were collected for major ions and isotopic analysis in autumn (November 2023) and winter (January 2024) respectively. Physicochemical parameters [pH, electrical conductivity (EC), dissolved oxygen (DO), oxidation-reduction potential (ORP), and temperature] were measured in situ by multi-probe. The major ions (Na^+, K^+, Ca^{2+}, Mg^{2+}, NH_4^+, SO_4^{2-}, Cl^-, HCO_3^-, NO_3^-) were analyzed in the laboratory for the Institute for Rural Engineering (NIRE) by using ion chromatography. Radon was extracted into the toluene scintillator and measured at NIRE using a liquid scintillation counter. For data analysis, cluster analysis (CA) using Ward linkage criteria and principal component analysis (PCA) were conducted using IBM SPSS 28.0 to investigate the predominant factors influencing hydrogeochemistry.

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Keywords: Water resources availability, hydrogeochemistry, Principal component analysis, Cluster analysis

3. Ongoing results and discussions

Chemical analysis of samples has revealed a slightly alkaline (mean value 7.50 in autumn and 7.47 in winter) nature of water. The cation concentration exhibited the sequence Ca^{2+}>Na^{+}>Mg^{2+}>K^{+} (mass per volume) in both seasons, suggesting the solubility of carbonate minerals, resulting in the release of Ca^{2+} and Mg^{2+} (Sun et al., 2010). Furthermore, the observed pattern may be attributed to the weathering processes affecting igneous rocks, which contain minerals rich in sodium ions (Sun et al., 2020). Regarding anions, dominance was noted in the order HCO_3^->SO_4^{2-}>Cl^->NO_3^-, indicating the prevalence of carbonate rocks in the geological context. The mean ratio of $(Ca^{2+}+Mg^{2+})/(Na^{+}+K^{+})$ exceeded 4 and $HCO_3^-/(Na^{+}+K^{+})$ surpassed 2 in both seasons, suggesting the influence of carbonate minerals like calcite and dolomite, supported by Fig. 2, with some samples (predominantly from ungrouped and cluster 2) exhibiting a low Ca^{2+}/Na^{+} equivalent ratio, indicating the influence of silicate mineral weathering. The $HCO_3^-/(HCO_3^-+SO_4^{2-})$ ratio, measuring 0.66 in autumn and 0.61 in winter, underscores the significance of carbonate and CO_2 dissociation processes in proton production (Pant et al., 2021). The Ca^{2+}/SO_4^{2-} ratio (2.32) in both seasons supports the dominance of H_2CO_3 over H_2SO_4 as the principal proton source in weathering (Ghimire et al., 2023).

In addition, PCA analysis of the autumn rendered three significant factors (Eigen value>1; KMO and Bartlett's test values greater than 0.6). The extracted factors explained 94.583% of the variance in water chemistry. Component 2 suggests potential human-induced contamination, while components 1 and 3 indicate the likelihood of geogenic contamination and rock-water interaction (Table 1). Regarding CA, cluster 1 is distinguished by low concentrations of Ca^{2+}, Mg^{2+}, Na^{+}, Cl^-, NO_3^-, SO_4^{2-}, and HCO_3^-, in contrast to the elevated levels observed in cluster 3. Additionally, cluster 2 exhibits intermediate concentrations relative to clusters 1 and 3, except for NO_3^-, which demonstrates the highest concentration among all clusters. Such differences further add validation to PCA results indicating the effect of geological differences and anthropogenic activities. The notable radon concentration at U05 and U08, averaging 3.35 and 10.35 Bq/L respectively across seasons, suggests significant subsurface rock-water interaction.

Although the percentage of sodium (Na%), sodium adsorption ratio (SAR), and salinity hazard values of the samples are within acceptable ranges, the permeability index (PI) indicated that R21 and R13 are unsuitable for irrigation. In future work, we'll explore seasonal hydrogeochemistry variations, tributaries discharge, and stable isotopic analysis for a better understanding of water resources availability.

Table 1 Factor loading of the PCA for ions of November's samples.

Variables	Components		
	1	2	3
EC	0.996	-0.026	0.004
pH	0.677	0.477	-0.160
Na^{+}	0.959	-0.177	-0.187
K^{+}	0.954	-0.222	-0.153
Mg^{2+}	0.973	0.042	0.186
Ca^{2+}	0.892	0.269	0.284
HCO^{3}-	0.921	0.209	-0.257
Cl^-	0.959	-0.161	-0.205
NO_3^-	-0.210	0.936	0.012
SO_4^{2-}	0.504	-0.077	0.854

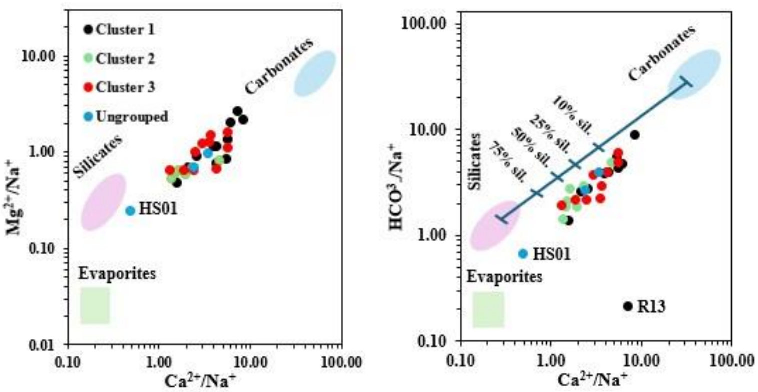

Fig. 2 Scatter plot showing the chemistry of November's samples.

Acknowledgments: The authors thank the Nanmoku Village office for their valuable information.

References: Ghimire et al. (2023). *Physics and Chemistry of the Earth*, Parts A/B/C, 129, 103349; Pant et al. (2021). *Chemosphere*, 279, 130496; Singh et al. (2020). *Journal of Geochemical Exploration*, 208, 106395; Sun et al. (2010). *Science of the Total Environment*, 408(20), 4749-4760; Sun et al. (2020). *Geoscience Frontiers*, 11(2), 697-713.