Hydrochemical Evolution of Water in the Crystalline Basement Aquifer in the Pra Basin (Ghana): Field Observations and Geochemical Modelling

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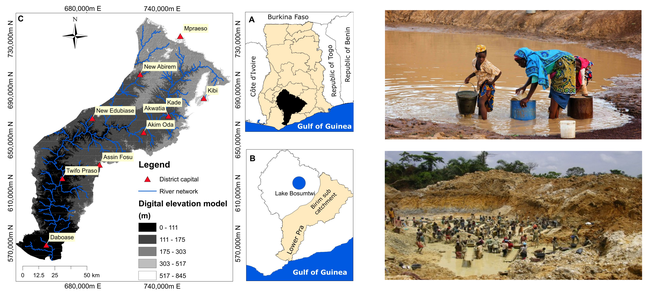
Motivation | Comprehending the chemical evolution of groundwater for water management

Groundwater is increasingly becoming the alternate source of water supply in the Pra basin of Ghana. Unfortunately, there is limited information available regarding the chemical characteristics and geochemical processes driving its composition, posing challenges to water management.

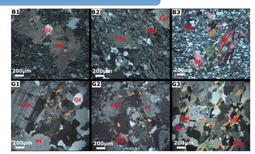


The study area showing pictures of land degradation from illegal mining activities which have caused many river bodies to become polluted. The size of the basin is approximately 10703 km².

Methods | Geochemical modelling of water-rock-interactions for quality assessment

Field sampling and measurements

- Surface water (34) and groundwater (56) samples were collected from rivers and boreholes respectively
- Water samples were analysed for their major ions, pH, total dissolved solids, electrical conductivity and dissolved oxygen [1]
- Outcrop samples were collected and petrographic thin-section analyses were performed [1]



Thin sections of rock outcrops for Birimian (B) and Granitoid (G) rock formation; biotite (bt), carbonate (cbt), sericite (srt). quartz (qtz), feldspar (fsp), muscovite (mvt).

Water quality assessment

- Computations of water quality were conducted using the Water Quality Index (WQI) proposed by Sahu and Sikdar [2]

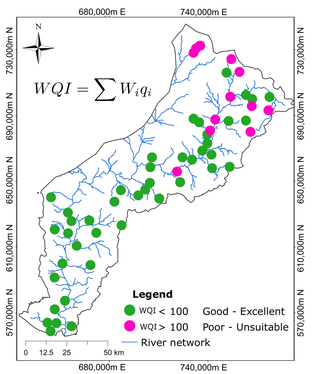
Statistical analysis

- Hierarchical cluster analysis was used to identify the natural groupings of the hydrochemical data

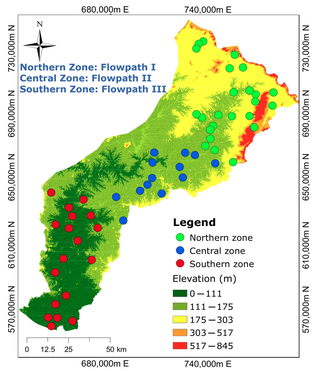
Combinatorial inverse and reaction path modelling

- PHREEQC and the RedModRphree package [3] were used for the modelling
- Thermodynamic concept of water-rock interactions are tested
- Multi-step combinatorial inverse modelling allowed field data calibration
- Reaction path modelling was implemented following a conceptual workflow

Data Analysis | Water quality assessment and hierarchical cluster analysis



Groundwater quality classification for drinking purposes established for the Pra basin [4].



Three hypothetical groundwater flowpaths delineated through cluster analysis [4].

References

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[3] De Lucia, M. and Kühn, M., (2021): Advances in Geo., 56,. DOI: https://doi.org/10.5194/adgeo-56-33-2021

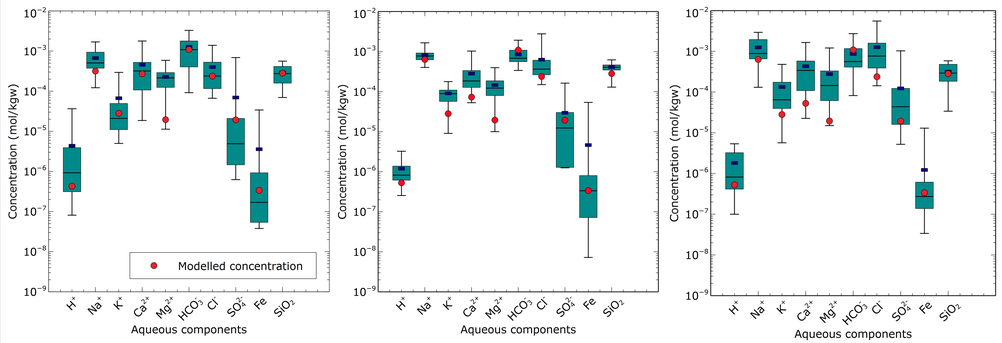
[4] Manu, E. et al. (2023b): Water, 15 (21) 3760. DOI: https://doi.org/10.3390/w15071325

[5] Manu, E. et al. (2023c): Mineral, 15 (21) 3760. DOI: https://doi.org/10.3390/min13070899

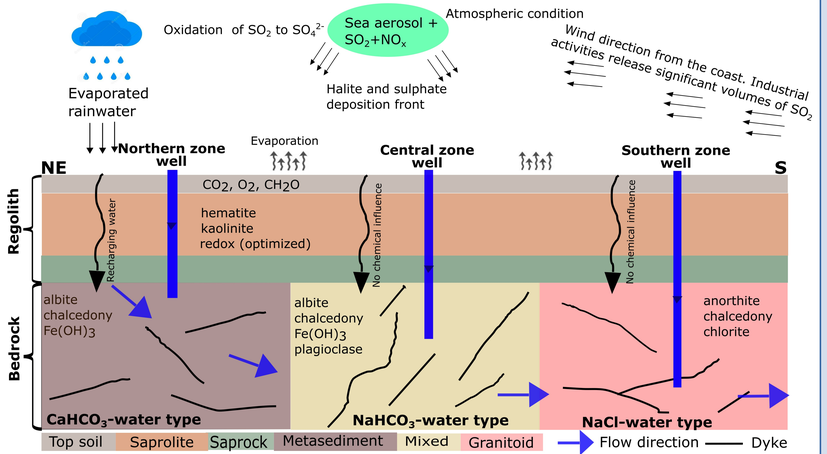
[6] Manu, E. et al. (2023d): Water, 15 (21) 3760. DOI: https://doi.org/10.3390/w15213760

Results | Mineral assemblages driving groundwater chemical evolution successfully derived from the combinatorial inverse modelling

- Three hypothetical flowpaths have been delineated and validated through the reaction path modelling
- Northern zone is identified as the main recharge area with water composition dominated by Ca-HCO_3 water type
- Central zone is characterised by Na-HCO_3 water type and represents the transition zone
- Southern zone is the discharge zone with its water composition mainly of NaCl water type



Modelled groundwater composition coincides with the observed concentration for all aqueous parameters along the three hypothetical flowpaths [5]. The discrepancy in the Ca^{2+}, Mg^{2+}, Na^{+} and K^{+} may be due to other factors such as mixing of surface water and kinetics which are not considered.



Conceptual model of chemical evolution of groundwater taking into account the rainwater origin [6] of the Pra Basin in Ghana. Mineral assemblages are derived from the best matched models from the combinatorial inverse modelling [5].

Conclusions | Baseline hydrochemical evolution of water quality established

- Groundwater is considered good for drinking except for the northern zone which requires Mn and Fe (total) treatment
- Sources of Mn and Fe in the groundwater could be traced from the underlying geology through water-rock-interactions and transport from the surface water
- Equilibrium-based thermodynamic concepts of water-rock interactions used to quantified the observed hydrochemical variations
- Weathering of silicate minerals is the dominant process driving the evolution of the groundwater
- Combinatorial inverse and the reaction path modelling enabled the development of a conceptual framework of the chemical evolution
- A new model has been developed to assess the quality of water resources in the Pra Basin and its applicable to other regions
- Subsequent research should incorporate reaction kinetics and mixing with surface water to reduce the uncertainties in the modelled concentrations

Acknowledgment

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