

Hydrogeochemistry of the groundwater flow system in a crystalline terrain: a study from the Kurunegala district, Sri Lanka

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Abstract Water samples collected from dug wells and tube wells from the Kurunegala District of Sri Lanka have been studied for their major hydrogeochemical parameters to understand the chemical quality of water in the terrain. The region is composed of Precambrian metamorphic rocks where groundwater is only available in the regolith and along weak structural discontinuities. The study of the major chemical constituents of groundwater revealed several relationships with the aquifer lithology. Groundwater from mafic rocks have high dissolved solids, while quartzose metaclastic rocks yield water with low dissolved solids. The study area displays very low SO_4^{2-} contents of the groundwater. The chloride content is higher in the dry regions and in terrains underlain by pink granite and marble/calc gneiss while areas with marble, as expected, show high concentrations of Ca and Mg ions. The waters in the region can be classified into non-dominant cations to Na + K dominant and Cl^- and HCO_3^- dominant types. Water from charnockite-bearing areas tends to have non-dominant cations and more $\text{CO}_3^{2-} + \text{HCO}_3^-$ types. Effects such as soluble salts in the regolith, fracture intensity and climatic variations play a significant role in the behavior of the hydrogeochemistry in the area.

Keywords Groundwater · Hydrogeochemistry · Precambrian terrain · Sri Lanka · Fracture zones · Climatic zones · Kurunegala district

Introduction

The population increase and concurrent demand for available water resources is a very well established fact (Wallace and Gregory 2002; Vörösmarty et al. 2006). The result of this demand is the water scarcity and increasing water stress as experienced by many regions around the equator (Oki and Kanai 2006). The water scarcity is especially true in the dry zone of Sri Lanka where the average yearly rainfall is less than 1,500 mm (Fig. 1). The sporadic rainfall received in the dry zone has a bimodal distribution (Fig. 2), which imposes difficulties in water supply to the growing population. The water competition index calculated for Sri Lanka was approximated to about 400 persons for one million cubic meters per year in 1980 with a predicted increase up to 500 during this millennium (Forkasiewicz and Margat 1980). With the population forecast at 23 million by the year 2025 (Intizar et al. 2000), Sri Lanka will face major water-related problems that would need thoughtful and detailed planning by the authorities. This is particularly relevant in the driest areas in Sri Lanka where there is an acute shortage of water. To face the problem, several state and private organizations are currently carrying out investigations to assess the availability and movement of groundwater in the sparsely distributed fractured aquifers located in the dry zone of Sri Lanka. In this respect, donor-driven projects implemented by the World Bank under Integrated Rural Development Projects (IRDP) in the 1980s and GTZ groundwater development projects in the 1990s can be cited. The socio-economic state and health

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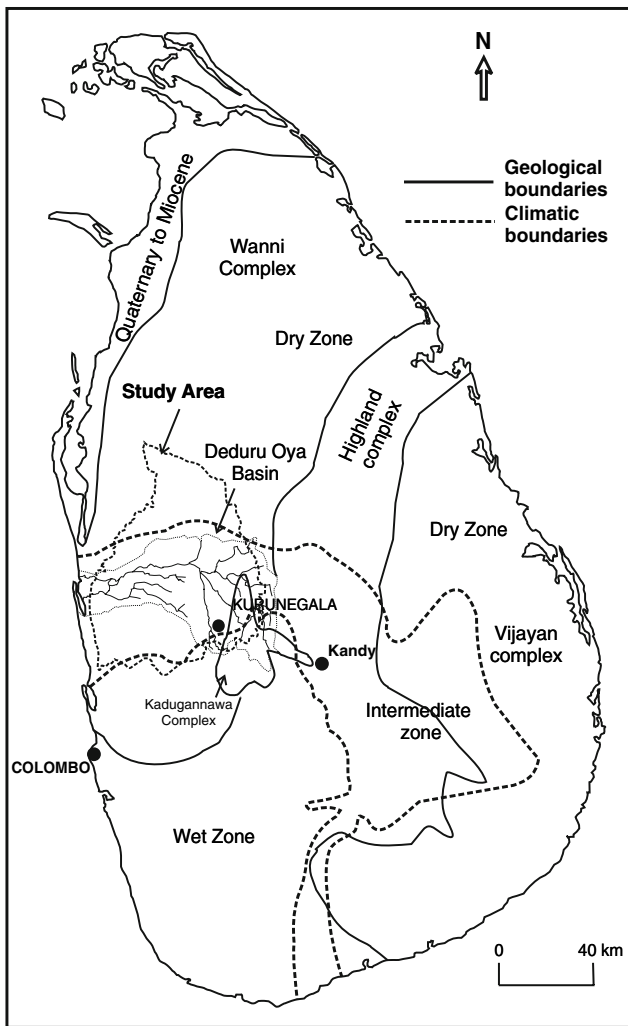


Fig. 1 The study region with respect to the major geological subdivisions (after Cooray 1994) and climatic zones of Sri Lanka

conditions of the people living in the dry zone were greatly enhanced and benefited by the groundwater provided through tube wells, which mainly penetrated the fractured aquifers. However, the evaluation of the quality of groundwater and interrelated hydrogeochemical processes are some of the important considerations in groundwater resources development (Hem 1991). Therefore, we attempt to evaluate the quality of groundwater and related hydrogeological conditions in a weathered and fractured aquifer lying in a part of Kurunegala district in the northwestern province of Sri Lanka.

Regional physiographic and geologic setting

Sri Lanka is a subtropical island with two well-distinguished major climatic zones known as the wet zone and dry zone (Fig. 1). In between the wet and dry zones, an

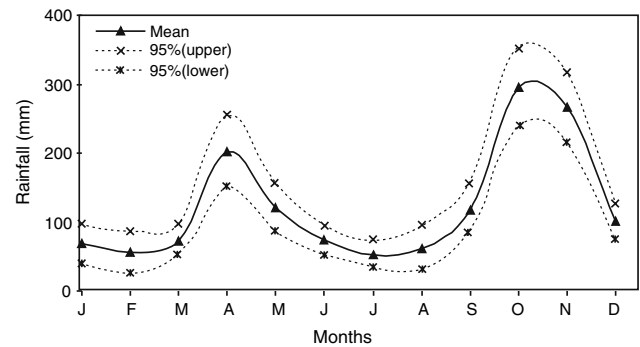


Fig. 2 Bimodal distribution of monthly rainfall for Wariyapola (30 year average from 1975 with 95% confidence intervals)

intermediate climatic zone has been recognized. The wet zone receives a mean annual rainfall of 2,500 mm mostly during the two monsoon seasons. The dry zone, which occupies two-thirds of the island receives a mean 1,000 mm of monsoon rains mostly from October to December. Most parts of the study area lie in the dry zone but the southernmost part falls in the intermediate zone. The Deduru Oya River is the major river draining the study area.

The study area is part of the Precambrian metamorphic terrain in northwestern Sri Lanka, composed mainly of ortho- and para-gneisses with several intrusions of granitic rocks. Sri Lanka consists of more than 90% Precambrian metamorphic rocks classified under three distinct lithological units (Fig. 1) namely Highland Complex, Vijayan Complex and Wannu Complex with the Kadugannawa Complex as a subordinate unit (Cooray 1994). Although there are a great variety of rock types within the study area, the vast majority is made up of quartzo-feldspathic granites, migmatites, hornblende biotite gneisses and charnockites with basic and ultrabasic rocks. Few exposures of quartzite, marble, calc-gneiss and cordierite biotite gneisses are also present in the eastern part the study area.

Rock weathering is known to be more intense in the “wet zone” of Sri Lanka than in the “dry zone”. The drier parts of the study area show a relatively shallow development of “in situ” soil profiles as compared to that of the wet zone. Structural discontinuities, such as faults, shear zones and joints, however, cause deep-seated weathering effects even in the dry zone, which have been observed during drilling. The effect of bedrock mineralogy could also be considerable since granites and other felsic rocks are typically weathered much deeper than ultramafic rocks. The structural discontinuities in quartzo-feldspathic rocks are also much higher, which ease the movement of water and other chemically active fluids into the deeper parts of the rock system. Cleaves (1974) and Leo et al. (1977) observed that the rocks containing abundant feldspars and quartz (felsic rocks) weather to kaolinite-bearing silt while

Table 1 Summary of chemical parameters for deep wells from the Kurunegala District, Sri Lanka

	Min	Max	Mean
pH	6.0	8.5	7.6
EC ($\mu\text{S}/\text{cm}$)	89	9,980	986
TDS	79	3,950	635
HCO_3^-	3.5	966	293
Cl^-	4.25	2,610	172
SO_4^{2-}	0.10	210	12.31
Ca	0.40	393	43
Mg	1.40	353	35.3
Na	1.20	611	92.3
K	0.50	72	7.00
Total hardness	19.0	2,039	270
Alkalinity	10.0	792	252

All values in mg/l except pH and EC

rocks containing abundant mafic minerals (ultramafic rocks) weather to montmorillonite-bearing silty soils. It was reported that the clay content of the highly weathered saprolite is generally about 5–10% but can be as much as 20% for mafic rocks (Obermeier and Langer 1986). Studies of soils in the dry zone of Sri Lanka show that the clay content in the saprolite varies from about 3.26 to 35%. Low

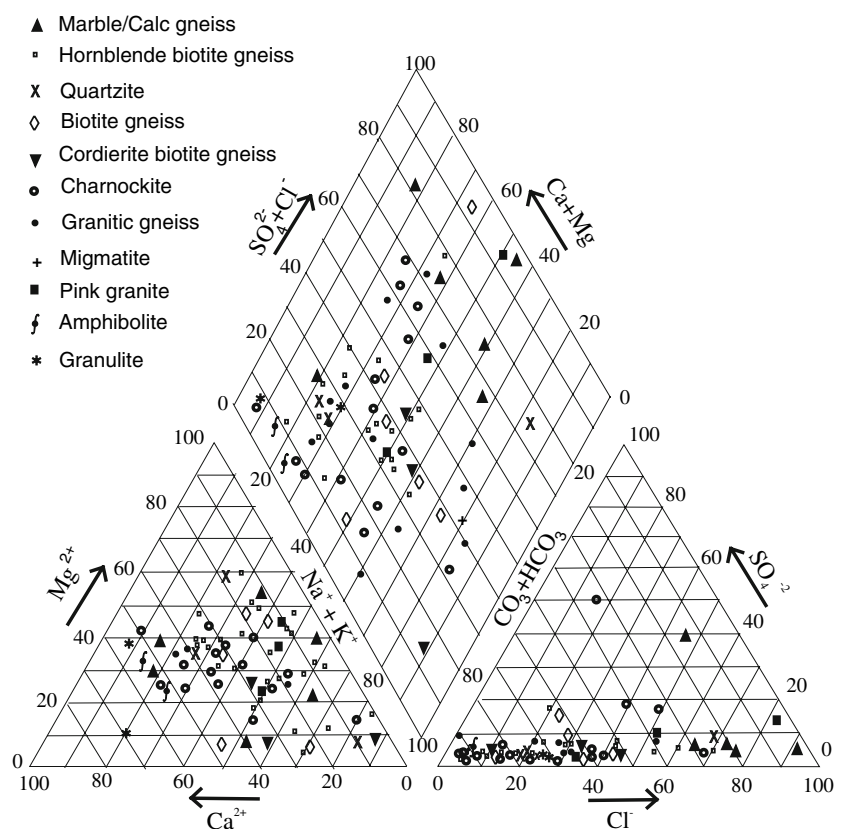
values were typically found in the well-drained soils in the highlands while high values were recorded in the imperfectly drained soils in the lower valleys and flood-prone regions (Panabokke 1996). The occurrence and movement of groundwater in the study area, therefore, is mainly controlled by the degree of weathering and structure.

Since groundwater constitutes an important source of water for domestic supply and agriculture in the dry zone regions of the country and its growing demand, the assessment of available groundwater is an important assignment. However, it is necessary to perceive the regional chemical variation of the flow regime and the results can be used to take preventive measures in groundwater contamination and develop groundwater for future demand. The area is ideal for this kind of study since the dry zone region is also partly encompassed within this block.

Materials and methods

For this study, water samples were collected from 240 shallow dug wells in the saprolite and from 90 deep wells drilled into the fractured aquifer. Sampling was carried out using precleaned polyethylene containers. Two samples were taken from each site of which one sample was acidified with analytical grade concentrated HNO_3 to prevent

Fig. 3 Piper diagram showing the distribution of major cations and anions for groundwater in the Kurunegala region



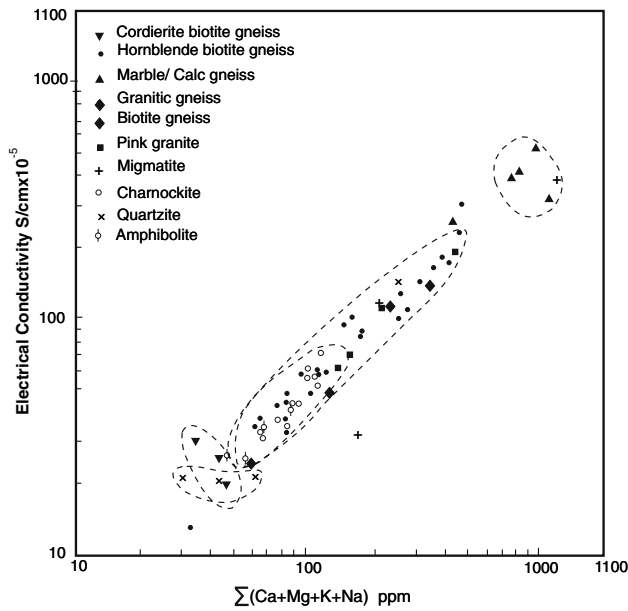


Fig. 4 Plot of $\Sigma(\text{Na}^+ + \text{K}^+ + \text{Mg}^{2+} + \text{Ca}^{2+})$ versus electrical conductivity for groundwater in different lithological units of Kurunegala region

the cations losses by adsorption or ion exchange with the walls of the container. The samples were analyzed for bicarbonate, hardness, chloride, sulfate, sodium, potassium, calcium, and magnesium using standard methods for the examination of water (APHA 1992). The pH and electrical conductivity (EC) were measured in the field, and anionic parameters of the water samples were measured within few hours of the sampling. The samples were refrigerated at

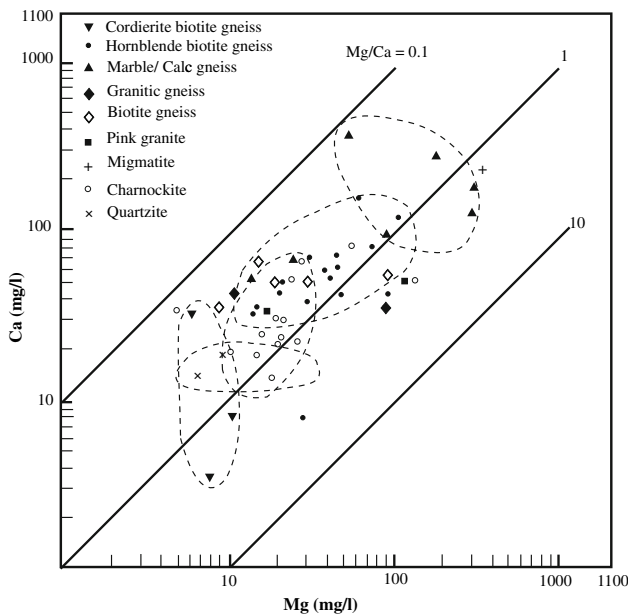


Fig. 5 Plot of Ca versus Mg in groundwater in different lithological units of Kurunegala district

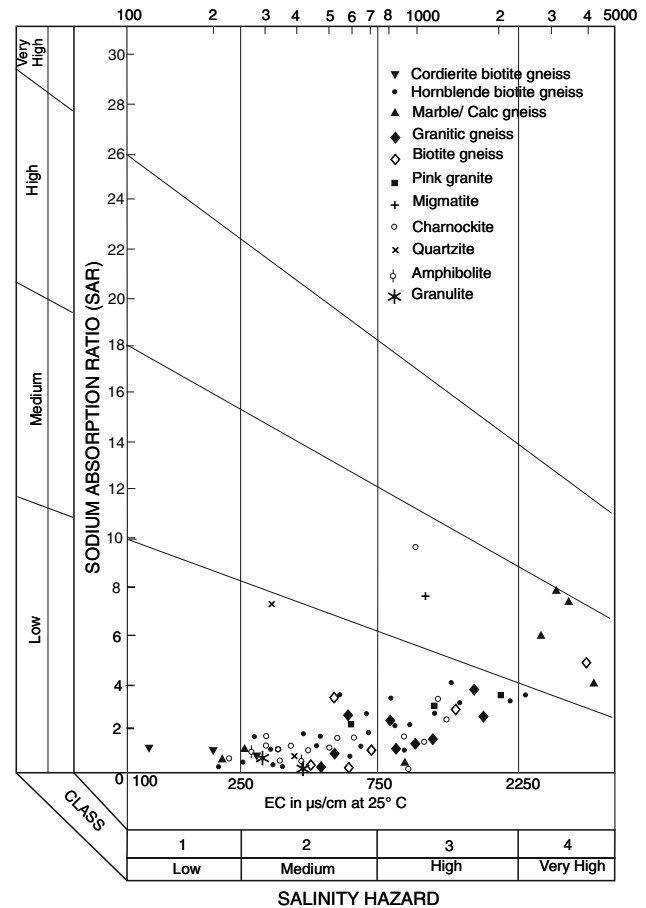


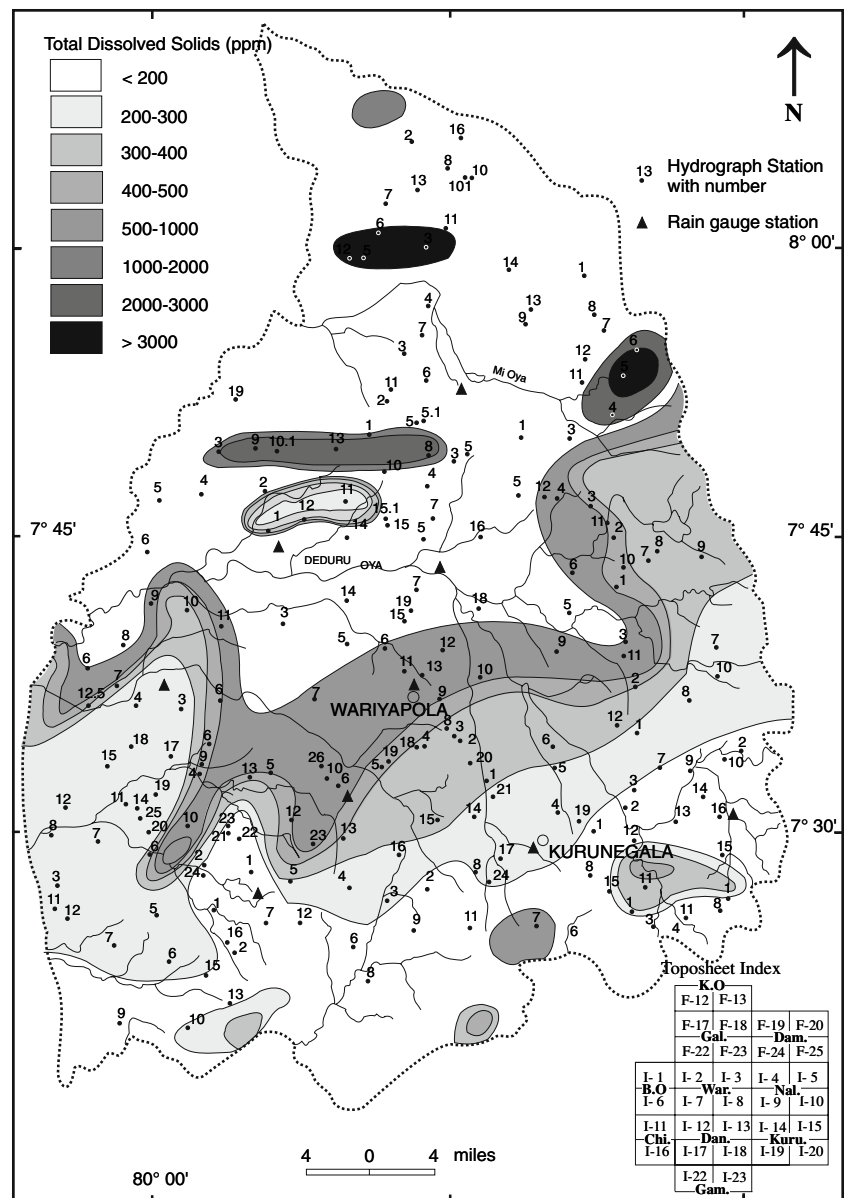
Fig. 6 Sodium absorption ratio versus salinity hazard diagram (US Salinity Laboratory Staff 1954) for the groundwater in the Kurunegala region

4°C and kept in the dark until the chemical analyses were carried out in the laboratory. The pH has been measured using a combination HANNA HI 8314 membrane pH meter, whereas the EC of the water was determined by Chemtrix Model Type 700. Total dissolved solids (TDS) were calculated using EC values, considering the relative ion concentrations. The bicarbonate, alkalinity, hardness (as CaCO_3) and chloride were determined by standard titration methods, whereas flame atomic absorption spectrometry (Perkin–Elmer 2380) was used for the determination of cations. Sulfate was measured using the Hach DR2010 spectrophotometer. All instruments were calibrated appropriately according to the commercial grade calibration standards prior to the measurements.

Results and discussion

The geochemistry of groundwater is influenced by factors such as the rock type, residing time in the rock, previous composition of the groundwater and other characteristics of

Fig. 7 Distribution of the total dissolved solids (TDS) in shallow wells of the Kurunegala district

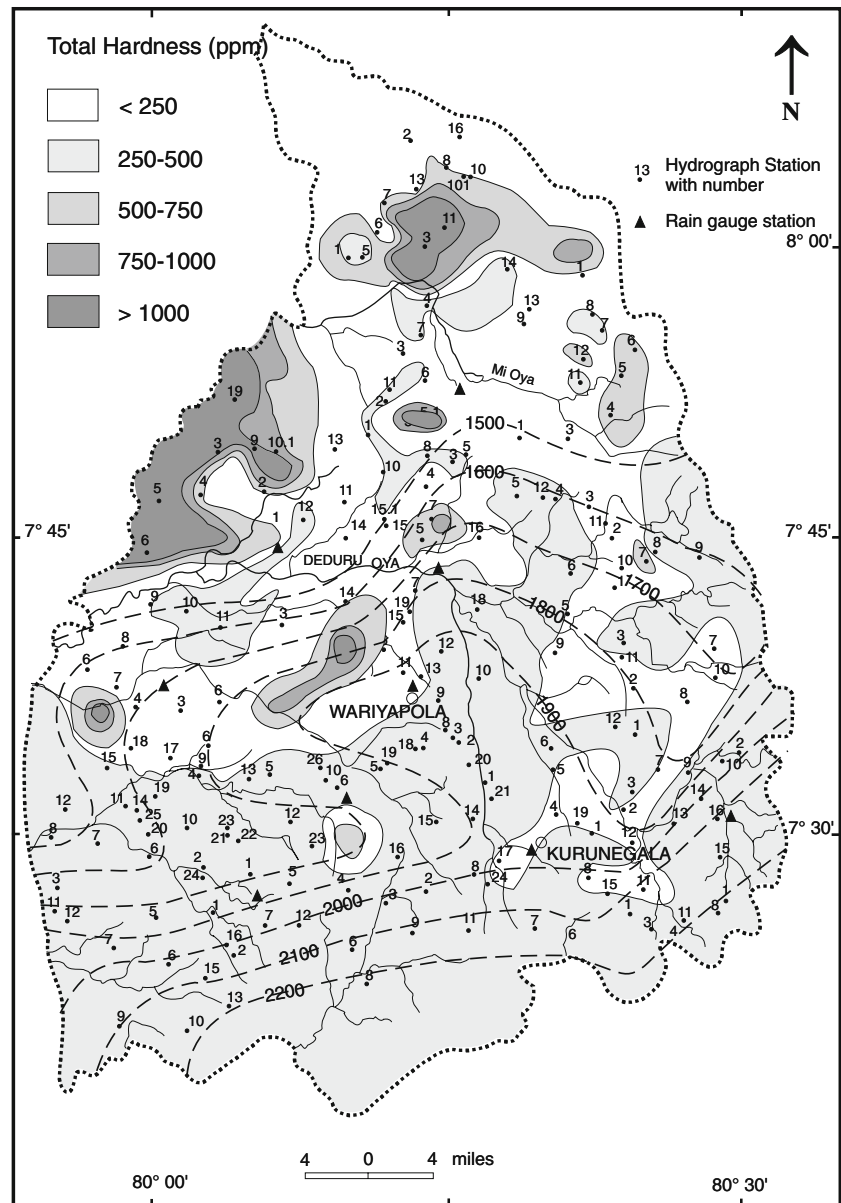


the flow path (Tóth 1999). Groundwater usually maintains a constant composition with time and may vary only slightly from well to well due to slower movement and longer residing time as compared to surface water in a given terrain (Corbett 1979). Table 1 shows the statistical summary of results of the chemical analysis of deep groundwater. The pH of the groundwater varied from 6.0 to 8.5 indicating a slightly alkaline nature. The TDS values varied from 79 to 3,950 mg/l in deep wells of which 83% of the wells had TDS values below 1,000 mg/l while only 2% showed TDS greater than 3,000 mg/l. The TDS values are higher in the northwestern part of the terrain and decrease towards the southeastern direction. However, few anomalies in some parts of the area can be observed, probably due to discrete water bodies, which are not

connected to the general groundwater flow system. The TDS in deep water is mostly comparable to that of shallow water particularly in the discharging areas close to Deduru Oya River. The average content of Na, K, Ca, and Mg ions in the deep groundwater in the region is 92, 7, 43 and 35 mg/l, respectively.

Figure 3 illustrates the Piper diagram representing the major cation and anion distribution in the study area. The groundwater in the area can be classified as non-dominant cations to Na + K dominant and Cl⁻/HCO₃⁻ dominant types. Most waters in the charnockite-rich terrains in the region tend to have non-dominant cations and more CO₃²⁻ + HCO₃⁻ types. In general, the sulfate contents in the groundwater are fairly low (average 12.3 mg/l) and the chloride content is high in the dry regions as well as in

Fig. 8 Distribution of the total hardness (mg/l) in deep aquifers of the Kurunegala district

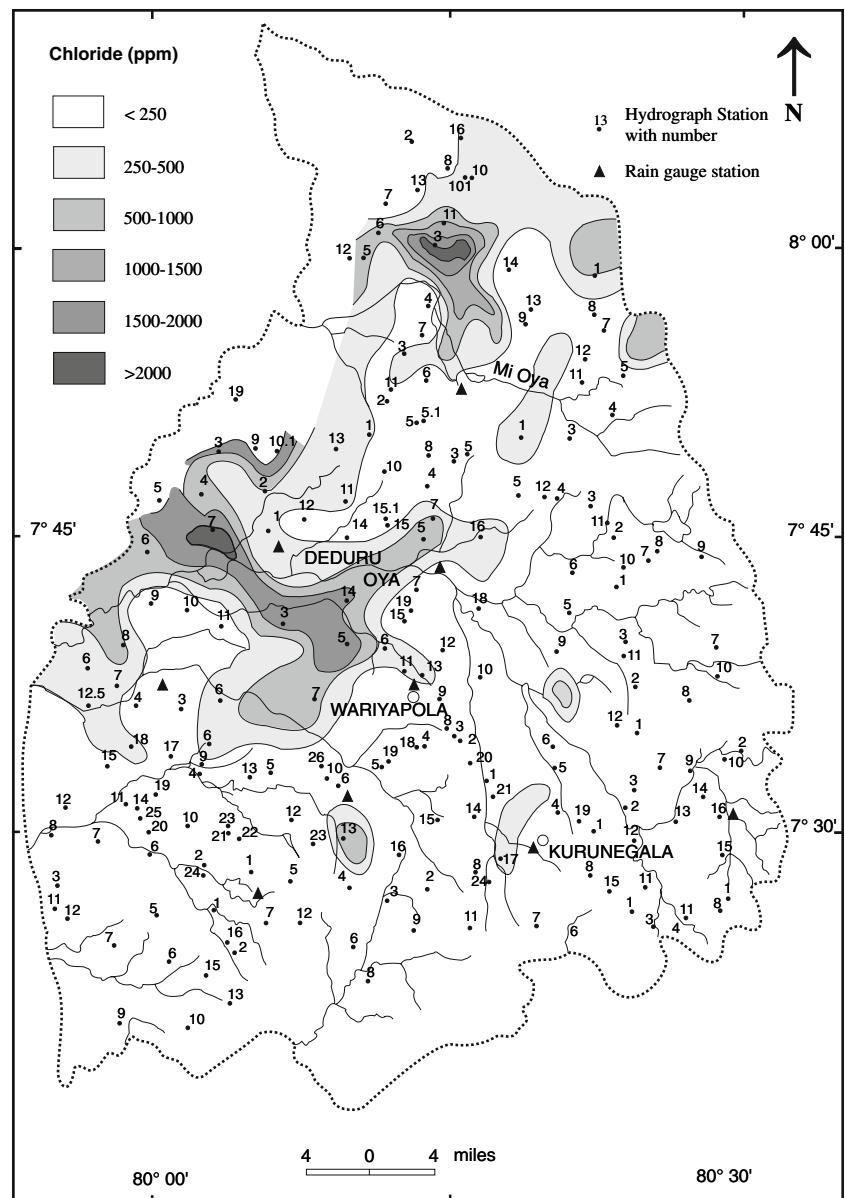


wells located in pink feldspar granite and marble/calc gneiss bearing terrains. In addition, several tube wells in the intermediate climatic region also show significant concentrations of these ions. Figure 4 illustrates the relationship between EC and $\Sigma(\text{Na}^+ + \text{K}^+ + \text{Mg}^{2+} + \text{Ca}^{2+})$ and a good positive correlation can be observed. The terrain underlain by mafic rocks shows higher EC values, hence higher TDS values, whereas water extracted from quartzose metaclastics rocks shows lower TDS content. The marble/calc gneisses and cordierite biotite gneiss terrains are clearly differentiated from the other regions with higher EC, higher alkali and alkaline earth metals. On the contrary, water from the cordierite biotite gneiss bearing wells shows lower EC and alkali and alkaline earth metals. Very similar differentiation can also be observed in Mg–Ca plot

and most wells are having the water with the Mg/Ca ratio between 0.1 and 1.0 (Fig. 5).

In order to evaluate the suitability of shallow groundwater for agricultural purposes, the chemical data were plotted on the sodium hazard versus salinity hazard diagram introduced by US Salinity Laboratory Staff 1954 (Fig. 6). The groundwater from wells in the marble and calc-gneiss terrain shows comparatively high salinity hazard and plot in the medium region of the sodium absorption ratio (SAR), probably due to high permeability of rocks causing accumulation of sufficient groundwater during rainy periods and leaving much salt during the dry periods where water is insufficient to leach them out or due to dissolution of Ca-bearing minerals in the circulating groundwater. Most groundwater from study area, however, plot in the medium-

Fig. 9 Distribution of chloride (mg/l) in deep aquifers of the Kurunegala district



to-high salinity hazard range with low SAR. Groundwater obtained from areas with pink granites, hornblende biotite gneiss and granitic gneisses in the dry zone area of the terrain lies in the medium-salinity hazard range.

Spatial distribution of TDS (Fig. 7), hardness (Fig. 8) and chloride (Fig. 9), in the shallow dug well waters indicate a close association with the rainfall pattern of the region (Fig. 8). However, few anomalies can be seen particularly in the northwestern and northern regions of the studied terrain, probably indicating the occurrence of few discreet water bodies, which are not directly connected to the general circulation of the groundwater. As shown in this study, the weathering is more intense in the wet zone of Sri Lanka than in the dry zone. However, localized changes such as deep percolation of groundwater can

increase the rates of weathering locally which directly affects the chemical quality of the water.

Conclusions

The geochemical composition of groundwater in the Kurunegala district of northwestern Sri Lanka indicates a direct relation between the lithology and relative abundance of cations. For instance groundwater from mafic rocks has high dissolved solids, whereas quartzose metaclastics yield water with low dissolved solids. In addition, few exposures of quartzite, marble/calc gneiss and cordierite biotite gneiss produce unique conditions in the development of groundwater as well as in the formation of recognizable

hydrogeochemical characters. Except for marble and calc gneiss, groundwaters from other rocks fall to low SAR regions, therefore water is suitable not only for drinking purposes, but also for agricultural purposes. However, climatic variation of the region also plays a significant role, as the water from dry regions contains more dissolved solids.

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References

- APHA (1992) Standard methods for the examination of water and wastewater, 18th edn. American Public Health Association, Washington DC
- Cleaves ET (1974) Petrologic and chemical investigation of chemical weathering in mafic rocks, eastern piedmont of Maryland. Maryland Geol Surv Report of Investigation, pp 25, 28
- Cooray PG (1994) The Precambrian of Sri Lanka: a historical review. *Precambrian Res* 66:3–18
- Corbett RG (1979) Geology and water characteristics. In: Panel on the geochemistry of water in relation to cardiovascular diseases (eds) *Geochemistry of water in cardiovascular disease*. National Academy of Sciences, Washington, D.C., pp 14–38
- Forkasiewicz J, Margat J (1980) *Tableau mondial de données nationales déconomie de l'eau*, Bureau de Recherches Géologiques et Minières. Département Hydrogéologie 79 SGN 784 HYD, Orleans
- Hem JD (1991) Study and interpretation of the chemical characteristics of natural water. Book 2254, 3rd edn. Scientific Publishers, Jodhpur
- Intizar H, Thirikawela S, Baker R (2000) Economic Analysis of residential, commercial and industrial uses of water in Sri Lanka, *Water International* 27(2):183–193
- Leo GW, Pavich MJ, Obermeier SF (1977) Mineralogical, chemical and physical properties of the regolith overlying crystalline rocks, Fairfax County, Virginia—a preliminary report. USGS. Open File Report 77–644, p 14
- Obermeier SF, Langer WH (1986) Relationships between geology and engineering characteristics of soils and weathered rocks of Fairfax county and vicinity, Virginia. US Geol Surv Prof Paper 1344
- Oki T, Kanae S (2006) *Global Hydrological Cycles and World Water Resources Science*, vol 313, pp 1068–1072
- Panabokke CR (1996) Soils and agro-ecological environments of Sri Lanka. NARESA, Colombo, p 220
- Tóth J (1999) Groundwater as a geologic agent: An overview of the causes, processes, and manifestations. *Hydrogeol J* 7:1–14
- US Salinity Laboratory Staff (1954) *Diagnosis and improvement of saline and alkali soils*: US Department of Agriculture Handbook, pp 60, 160
- Vörösmarty CJ, Green P, Salisbury J, Lammers RB (2006) Global Water Resources: vulnerability from climate change and population growth. *Science* 289:284–288
- Wallace JS, Gregory PJ (2002) Water resources and their use in the food production. *Aquat Sci* 64:363–375