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Controls of evaporative irrigation return flows in comparison to seawater intrusion in coastal karstic aquifers in northern Sri Lanka: Evidence from solutes and stable isotopes

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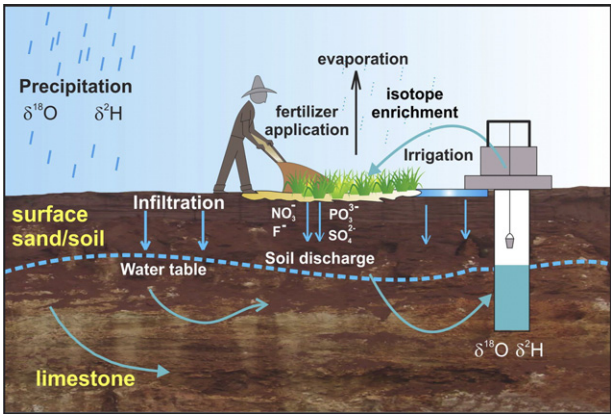
HIGHLIGHTS

- Miocene limestone aquifers are the main source of drinking water in the Jaffna region, Sri Lanka.
- This work investigated the processes governing the groundwater composition.
- Major solute geochemistry and isotopes of $\delta^{18}O$ and $\delta^{2}H$ were employed.
- Groundwater quality is degraded and highly modified by human activities.
- Stable isotopes and water chemistry indicate that evaporation dominates over seawater intrusion.

GRAPHICAL ABSTRACT



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ABSTRACT

Groundwater in Miocene karstic aquifers in the Jaffna Peninsula of Sri Lanka is an important resource since no other fresh water sources are available in the region. The subsurface is characterized by highly productive limestone aquifers that are used for drinking and agriculture purposes. A comprehensive hydrogeochemical study was carried out to reveal the processes affecting the groundwater quality in this region. Major and trace element composition and environmental isotope ratios of oxygen and hydrogen ($\delta^{18}O_{H2O}$ and $\delta^{2}H_{H2O}$) were determined in 35 groundwater samples for this investigation. The ion abundance of groundwater in the region was characterized by an anion sequence order with $HCO_3^- > Cl^- > SO_4^- > NO_3^-$. For cations, average $Na^+ + K^+$ contents in groundwater exceeded those of $Ca^{2+} + Mg^{2+}$ in most cases. Ionic relationships of major solutes indicated open system calcite dissolution while seawater intrusions are also evident but only close to the coast. The solute contents are enriched by agricultural irrigation returns and associated evaporation. This was confirmed by the stable isotope composition of groundwater that deviated from the local meteoric water line (LMWL) and formed its own regression line denoted as the local evaporation line (LEL). The latter can be described by $\delta^{2}H_{H2O} = 5.8 \times \delta^{18}O_{H2O} - 2.9$. Increased contents of nitrate-N (up to 5 mg/L), sulfate (up to 430 mg/L) and fluoride (up

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to 1.5 mg/L) provided evidences for anthropogenic inputs of solutes, most likely from agriculture activities. Among trace elements Ba, Sr, As and Se levels in the Jaffna groundwater were higher compared to that of the dry zone metamorphic aquifers in Sri Lanka. Solute geochemistry and stable isotope evidences from the region indicates that groundwater in the area is mainly derived from local modern precipitation but modified heavily by progressive evaporative concentration rather than seawater intrusion.

1. Introduction

Groundwaters in karstic terrains are important because nearly 25% of the world population rely on karst aquifers for potable water supply (Ford and Williams, 2007). However, karst aquifers are also highly vulnerable due to usually short residence times of groundwater in the system. Such karstic aquifers are often complex and heterogeneous (Bakalowicz, 2005; Romanov et al., 2003; White, 2002; Wu et al., 2009). They are often characterized by open conduits that provide low resistance pathways to water infiltration as well as various solutes originating from anthropogenic or natural sources. In karst aquifer systems, the geochemical evolution of groundwater is controlled mainly by the composition of recharge water, while characteristics of the aquifer material and contaminations from surface activities also play a role (White et al., 1995; Wu et al., 2009). Groundwater is a vital water source in karst areas, where surface water resources are often absent. Therefore, an improved understanding of geochemical evolutions of groundwater in such regions is important.

Only 9% of the land area of Sri Lanka consists of Miocene limestone sequences that are confined to the north and northwestern part of the island (Fig. 1). These limestone formations are characterized by shallow confined karstic aquifers that occur in channels and cavities of carbonate rocks (Panabokke and Perera, 2005). In this Miocene carbonate belt, groundwater resources occur as a series of several isolated hydrological basins (Basnayake, 1988; Davis and Herbert, 1988) with four main karstic confined aquifers. They are known as Chunnakam (formerly Valikamam), Thenmaradchi, Vadamarachchi and Kytes, which encompass the northern Jaffna peninsula (Davis and Herbert, 1988). Since the region is characterized by a semi-arid climate, these groundwater resources play an increasingly important role in agriculture and domestic water supply.

These Miocene aquifer systems were therefore subject to several earlier studies with particular attention to pollution (Dissanayake and Weerasooriya, 1987; Gunaalan et al., 2015; Hidayathulla and Karunaratna, 2013; Joshua et al., 2013; Nanthini et al., 2001; Nishanthiny et al., 2010; Thushyanthy and De Silva, 2012). Most of these studies, however, considered only few geochemical parameters such as nitrate and phosphate that are attributed to anthropogenic activities such as fertilizer applications and septic tank leaching (Dissanayake and Weerasooriya, 1987; Joshua et al., 2013). In recent years, the Jaffna region was subject to substantial land-use changes. Therefore an improved understanding of geochemical processes that govern the composition of groundwater becomes apparently important for water resource management and environmental protection in the region. Moreover, most of the terrain is surrounded by the Indian Ocean (Fig. 1) and intrusion of saline waters becomes a realistic threat to aquifers, in addition to the anthropogenic pollution. So far little is known about the natural processes such as rock-water interaction or seawater intrusion that could strongly influence the geochemical compositions of karst aquifer water in this region.

In this study, karstic groundwater resources in the semi-arid Jaffna peninsula were investigated by hydrogeochemical and stable isotope data. These techniques help to outline various processes such as timing of recharge, water-rock interactions and mixing of different water types (Bakalowicz, 2005; Chandrajith et al., 2014; Kanduč et al., 2012; Lang et al., 2006; Thilakerathne et al., 2014; van Geldern et al., 2015; Yousif et al., 2016; Zavadlav et al., 2013). In addition to geochemical characterization of the groundwater, we also investigated the geochemical processes and factors that control the composition of groundwater in this karstic terrain. Such information is important for future groundwater management in the area where surface water resources are extremely scarce. This study is also representative for other near-shore karst areas worldwide where seawater intrusion and water scarcity constrain groundwater resources that are already under pressure from anthropogenic pollution impacts.

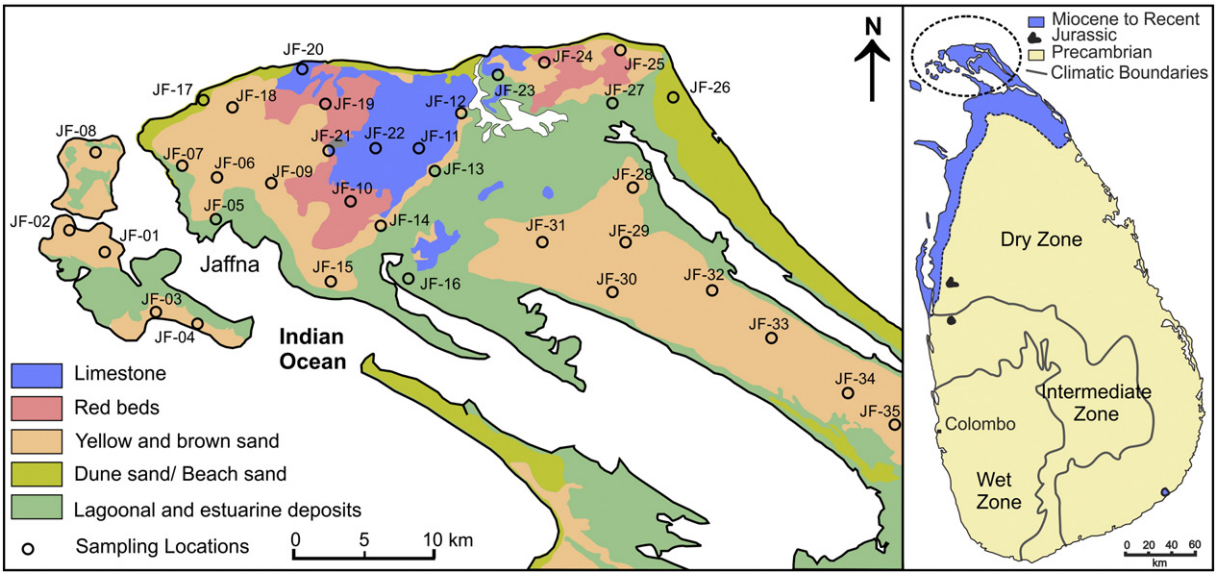

Fig. 1. Simplified geological map of the study area and sampling locations.