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Water Rock Interaction [WRI 14]

Isotopic and geochemical tracers in the evaluation of groundwater residence time and salinization problems at Santiago Island, Cape Verde

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Abstract

Stable isotopes ($\delta^{18}O$, δ^2H) and tritium (^3H), together with geochemistry and geophysical data, were used for evaluating groundwater recharge sources, flow paths, and residence times in a watershed on Santiago Island, Cape Verde, West Africa. Stable isotopes indicate the predominance of high-elevation precipitation that undergoes little evaporation prior to groundwater recharge. Low tritium concentrations at seven sampling sites indicate groundwater residence times greater than 50 years. Higher tritium values at other locations suggest more recent recharge. Young ages indicate local recharge and potential groundwater vulnerability to surface contamination and/or salt-water intrusion. Geochemical results indicate that water–rock interaction mechanisms are the major processes responsible for the groundwater quality (mainly calcium-bicarbonate type), reflecting the lithological composition of subsurface soil.

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Keywords: Santiago Island, Cape Verde - West Africa; stable isotopes; groundwater age; groundwater quality; seawater intrusion.

1. Introduction

Salinization of groundwater resources is one the most widespread processes that degrades water-quality and endangers future water exploitation in coastal areas in particular in arid and semi-arid regions.

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The problem is intensified in coastal aquifers, where human activities result in accelerating water-quality deterioration in particularly in arid and semi-arid regions. Santiago Island is part of the Republic of Cape Verde, located about 500 km west of Senegal, Africa (Fig. 1a). Because of its proximity to the equator, seasonal average daily temperatures vary around 5°C throughout the year from 22–27°C and total annual precipitation ranges from 0–50 mm along the populated coastal areas to 400-1000 mm in the highlands (Pico da Antónia or Serra da Malagueta) and is extremely variable from year to year [1]. Most of the precipitation is lost due to evapotranspiration and runoff to the sea, caused by a combination of warm climate, thin soil cover, and steep topographic gradients. Surface-water resources are virtually non-existent; only a few small perennial streams. The majority of the population resides in rural areas and gets its livelihood from rain-fed agriculture. Nearly all of the water for consumption comes either from rainfall catchment structures or groundwater [1]. The semi-arid to arid climate of Santiago Island, with unreliable and erratic rainfall, leads to prolonged drought periods. In fact this situation is responsible for quasi-periodic and sometimes catastrophic aridity.

Under the R&D Project "HYDROARID – Evaluation of the Hydrogeological Potential and Sea Water Intrusion Monitoring in Semi-Arid Zones Using a Multitechnique approach: application to the Santiago and Maio Islands (Cabo Verde)", fieldwork campaigns were carried out at Santiago Island (Fig.1b). The aim of this study was to evaluate the application of environmental isotope and geochemical methodologies to find answers to hydrogeological questions such as: (i) What is the origin and mechanisms of groundwater recharge? (ii) What is the relation between shallow and deep aquifer systems? (iii) How severe is the saltwater intrusion problem? (iv) What is the apparent groundwater age?

2. Study Area—Local Geology and Hydrogeology

The Cape Verde archipelago experiences semi-arid climate, with a major influence provided by the Sahara desert on mainland Africa to the east (Fig 1). The rainy season extends from July-August to October-November, with precipitation being mainly orographic. Mean annual precipitation is 323mm, over its 1000 km^2 surface area. The water balance calculations indicate that runoff amounts to 18% of the precipitation which discharges directly to the sea, while just 13% of the precipitation becomes infiltration to the soil [1]. Three main hydrogeological units have been identified on Santiago Island, which are linked to the island's volcanic origins: (i) the oldest Basal Unit, a Lower Palaeogene - Middle Miocene complex consisting of compacted, low-permeability formations; (ii) the Intermediate Unit, a thick and extensive eruptive formation consisting of basaltic pillow lavas and pyroclastic rocks that is characterized by a high permeability and is the principal aquifer system; and (iii) the Recent Unit comprised of highly permeable pyroclastic cones through which input water readily leaks through into the Intermediate Unit. Alluvial sediments from the Pliocene-Pleistocene fill most of the stream valleys, especially in their terminal sections. Intensive agricultural practices occur within these fertile soil valleys [3]. In this particular hydrogeological environment low-permeability clay layers intercalated with sand formed by the weathering of the upper lava flows may also act as hydraulic barriers. Such horizontal and vertical flow barriers may cause perched groundwater, high-altitude springs, and/or groundwater compartmentalization resulting in a stepped and discontinuous water table (see Fig. 1c). Oceanic islands typically have a low-density freshwater lens of groundwater overlying higher-density brackish and saltwater. Under steady-state conditions, the freshwater hydraulic head is above sea level. The fresh water/brackish water boundary is generally controlled by pressure and density and is dependent on the balance between groundwater recharge and groundwater discharge. Therefore, aquifer drawdown associated with excessive pumping, may lower water levels in the aquifer and move the fresh/brackish water boundary upward and inland, causing salt-water intrusion