

The limestone aquifers of Malta: their recharge conditions from isotope and chemical surveys

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Abstract The potable water supply in Malta is heavily dependent on groundwater. The two main aquifers, the Perched Aquifer and the Mean Sea Level Aquifer (MSLA), are vertically stacked and separated by impermeable formations. Groundwater is now being threatened by over-pumping and pollution. An isotope and chemical survey was undertaken on rain and groundwater to identify the recharge conditions and set new strategies for exploiting and protecting groundwater. The main results show that: (a) an elevation effect does not appear in rainwater $\delta^{18}\text{O}$, so that groundwater cannot be distinguished in either of the aquifers by means of stable isotopes, and (b) groundwater tritium content shows an old recharge of MSLA and a very long residence time. Tritium results look inconsistent with other data, suggesting a present day recharge split into two components: a rapid portion through fractures, and a slow portion through rock porosity which is dominant.

Key words environmental isotopes; groundwater resource; karst; Malta; Mediterranean island hydrogeology; natural tracing; tritium

INTRODUCTION

The Maltese islands obtain their potable water supply from groundwater and seawater desalination in equal proportions. Groundwater is mainly extracted by means of draining galleries in the saturated zones of the two main aquifers found in limestones; the Perched Aquifer (PA) and the Mean Sea Level Aquifer (MSLA). Groundwater is currently endangered by seawater intrusion due to over-pumping from irrigation wells, and by various forms of domestic and agricultural pollution resulting in a significant nitrate contamination of both aquifers.

Various hydrogeological studies have been conducted since the 1950s (Atiga, 1970). BRGM (1991) and Gutierrez (1994) developed two three-dimensional models simulating the MSLA in structure and flow as affected by annual recharge, and abstraction from boreholes and a network of 40 km of sea-level galleries. This model provided an efficient tool for groundwater resources management, but it needs fresh revisions to reflect today's growing number of unmonitored boreholes. Moreover, the degradation of groundwater quality as a result of seawater intrusion and pollution is often interpreted as a result of high aquifer vulnerability in a karst environment (De Ketelaere, 1995, 1996).

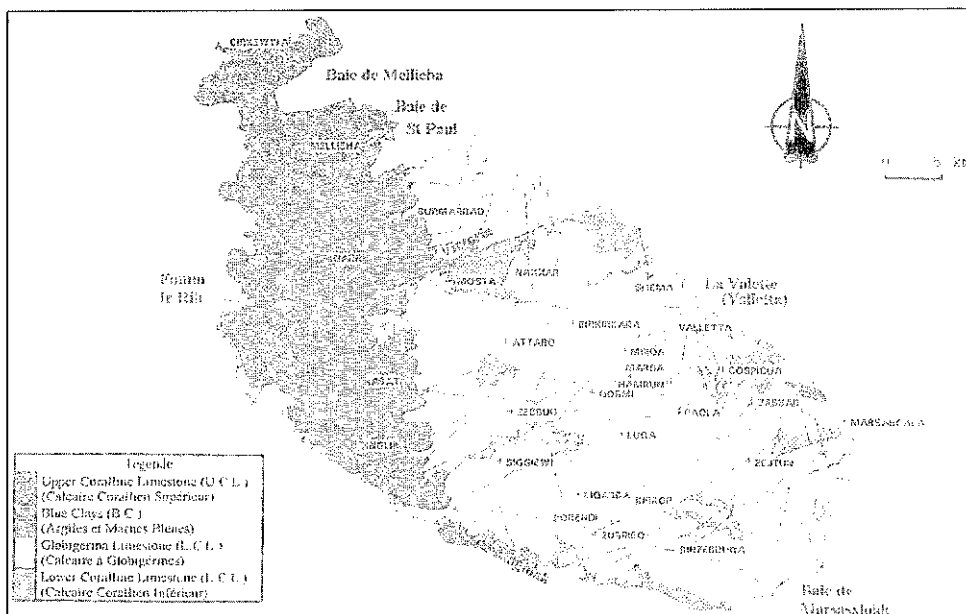


Fig. 1 Geological map of Malta Island.

However, Gutierrez (1994) considered that karst phenomena, which are scarce, should not play any significant role in the aquifer functioning at a regional level. Finally, the recharge conditions were still unclear and they need to be investigated further if the MSLA is to be sustainably managed. Hence, an isotope and chemical survey was undertaken with the aim of improving knowledge on the recharge dynamics of the Maltese aquifers. A survey of karst features at the ground surface and in the aquifer along some draining galleries, was carried out to determine the role of karst in groundwater flow. The first results are presented and interpreted in this paper.

HYDROGEOLOGICAL SETTING

Geology

The geology of the Maltese islands comprises a succession of Tertiary limestones and marls from the top of Oligocene to the Miocene, with scarce Quaternary deposits (Fig. 1). Basically the succession consists of a central core of clays and marls, the Blue Clay (Serravallo–Tortonian) and the Globigerina Limestone formations stacked between the Upper (Tortonian–Messinian) and Lower Coralline Limestone formations. The Lower Coralline Limestone consists of a series of biomicrites, rhodolitic and bioclastic limestones. The Upper Coralline Limestone, composed of highly fossilized, coarse bioclastic, is characterized by its heterogeneous lithology.

As the islands lie on the eastern edge of the north-African continental shelf, Tertiary movements gave rise to a series of horst and graben structures running in a NE–SW direction and a predominant regional slight dip to the northeast. A major fault

(Victoria fault) striking ENE–WSW separates the island into two regions: the upthrow side to the south, where topography is relatively flat, and the downthrow side where the terrain is hilly (Fig. 1). This fault is of hydrogeological relevance.

HYDROGEOLOGY

These geological features give rise to two types of unconfined aquifers namely, the mean sea-level aquifers and the perched aquifers. The *Mean Sea-Level Aquifers* are freshwater lenses found in the Lower Coralline Limestone at sea level. The largest and by far the most important for the public supply, is the Mean Sea-Level Aquifer (MSLA) of Malta that extends over an area of 216 km² south of the Victoria fault. This aquifer is the subject of our case study. To the north of the fault the aquifer is locally depressed below sea level and overlain by the Blue Clays in western Malta. MSLA does not have the generally high permeabilities of coral reefs, but instead the highly irregular permeability that characterizes algal reefs. Primary porosity varies from 7 to 20%, while primary permeability is rather low. Effective porosity and secondary permeability are mainly fissure dependant and estimated to range 10–15% while the average hydraulic conductivity measured from pumping tests is $400 \times 10^{-6} \text{ m s}^{-1}$. Transmissivity varies between 10^{-4} and $10^{-3} \text{ m}^2 \text{ s}^{-1}$.

The MSLA is in contact with seawater and reaches a piezometric height of around 3 m above sea level. The structure of the lens implies an outflow gradient towards the sea, discharging to the sea in a diffuse manner through rock porosity and micro-fissures, or occasionally in concentrated small brackish springs. In practice, the MSLA are very sensitive to seawater upconing due to their hydrogeological characteristics. To overcome these constraints, galleries excavated in the saturated zone were designed to draw water from the relatively thin freshwater lenses. Groundwater collected from these galleries for the past century is pumped and continues to be an important source of drinking water.

The *Perched Aquifers* are small aquifers found in the Upper Coralline Limestone which occurs in the Rabat-Dingli Plateau and separate faulted blocks. They are still being exploited for public supply purposes and offer potential for groundwater storage. At the border of the ridges, some of them discharge through springs that are only used for irrigation as they are heavily polluted. The primary porosity of the Upper Coralline Limestone ranges between 41 and 45% with a low permeability of around $1 \times 10^{-6} \text{ cm s}^{-1}$.

Infiltration into both types of aquifers is through cracks, fissures and rock porosity. The infiltration zone of the MSLA is generally 50–100 m thick, while it is thinner in the PA (20–50 m). At the surface, the aquifers are overlain by thin soil cover. MSLA is partly overlain by the Globigerina Limestone, which is an aquitard, and transmits water mainly through fissures. Fracturing is aligned parallel to the NE–SW faulting and horst-graben structure (Gutierrez, 1994), while karst solution features are related, as usual, to the faulted and fractured zones (De Ketelaere, 1996). We directly observed that the galleries of the Ta’Kandja pumping station, dug for draining the MSLA, cut through some fractures that do not show any karst features close to the water table. However, during the digging works, “caves” were encountered twice and open fractures were encountered several times.

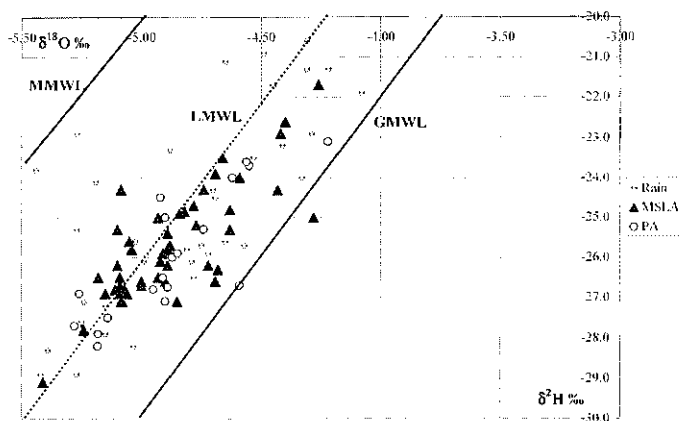


Fig. 2 $\delta^{18}\text{O}$ vs $\delta^2\text{H}$ in rain and groundwater, from Malta. Summer evaporated rainwater and groundwater mixed with seawater are not displayed. MSLA: Mean Sea Level Aquifer. PA: Perched Aquifer. The three lines with a slope of 8 display the global (GMWL), local (LMWL) and Mediterranean (MMWL) relationships.

Karst phenomena are not very common at the surface, except in the Upper Coralline Formation of the Rabat Plateau. Morphology is generally dominated by surface erosion landforms and the scarcity of underground karst in the Lower Coralline Formation reflects surface landscape conditions. The few known caves, hydrologically inactive and filled with sediments, indicate a different base-level that could be the remains of an old karst, now eroded or flooded by the sea. According to these observations, cracks and rock matrix porosity could play an important part in groundwater flow and in recharge processes, while fractures and faulted zones should only affect the aquifer locally.

METHODS AND MAIN RESULTS

A network of sampling sites was identified for the collection of rain and groundwater samples from springs and pumping stations. Samples were taken at two-month intervals during 2001 and 2002 for isotope (^{18}O , ^2H , ^3H) and chemical analyses, from nine sites in the MSLA bore holes and galleries, and four sites in the PA. Six other sites in the MSLA were also tested less regularly for control purposes. Sampling of rainwater was done, when possible, after heavy rainfall at 11 stations. A total of 75 groundwater samples were analysed in IAEA laboratories for ^{18}O and ^2H , 34 for ^3H ; 89 rainwater samples for ^{18}O and ^2H , and 44 for ^3H . Seventy groundwater samples were analysed by the Water Services Corporation laboratory, for their major ion composition (Na, K, NO_3 , SO_4 , Cl), after determination of temperature, pH, electrical conductivity in the field, and alkalinity, total hardness, calcium and magnesium hardness, by classical titrimetric methods.

In a $\delta^{18}\text{O}$ vs $\delta^2\text{H}$ diagram, the rainwaters are situated between the global meteoric water line and the Mediterranean meteoric water line (Fig. 2). No altitude effect is evident on a $\delta^{18}\text{O}$ -altitude diagram, because of the generally low elevation (maximum

altitude in Malta 258 m a.s.l.) and the prevailing topography of the island. An evaporation effect is observed in summer rainwater, but not in groundwater. The tritium content in rainwater is in the range 2.6–11.2 TU (average 5.5 TU). Groundwater tritium content is generally very low in groundwater from the MSLA, ranging from 0.2 to 3.1 TU, most of it being lower than 1.5. In the PA, tritium ranges between 1.9 and 7.4 TU.

Results of chemical analysis indicate that NO_3 content varies between 26.6 and 69.1 mg l^{-1} in the MSLA (average 48.7 mg l^{-1}), and 39.9–172.8 mg l^{-1} in the PA (average 99.5 mg l^{-1}). Cl as well as SO_4 , Mg, Na and K, are related to salinization of the aquifers, so that Cl alone is considered here. Cl content varies from 120 to 2305 mg l^{-1} in MSLA (average 650 mg l^{-1}) and from 140 to 270 mg l^{-1} in PA (average 206 mg l^{-1}).

DISCUSSION AND FINDINGS

Owing to the absence of an altitude effect in stable isotope content of rain and groundwater, one cannot distinguish PA and MSLA groundwater by means of isotopes. However, groundwater from both aquifers can be distinguished by natural tracing. In addition to Cl, which characterizes the seawater intrusion in MSLA, tritium and nitrate contents are significantly much lower in MSLA than in PA groundwater. Tritium levels ≤ 1.5 TU mean that the recharge is old in MSLA and the residence time longer than 40 years. Moreover, tritium and NO_3 contents measured in MSLA groundwater at Fiddien bore hole suggests that downward leakage may recharge the MSLA at least locally from the PA below the Rabat-Dingli plateau. Leakage probably occurs along fractures through the 70 m thick core of impermeable beds.

These data show that MSLA cannot be considered to be shielded from surface pollution coming from the plateau. Furthermore, long groundwater residence time suggests that karst features do not play any significant role in the dynamics of groundwater flow. This is consistent with field observations. However, the presence of NO_3 at concentrations up to 69 mg l^{-1} suggests a recent recharge of MSLA with water contaminated by agriculture and/or sewage water. These data are not fully consistent with hydrological data, which show that during rain events the water head in both aquifers may vary significantly in some places, but slowly to very slowly in others.

CONCLUSIONS

Groundwater quality should therefore reflect the result of a mixing process between two recharge components: (a) a very slow component, moving through fine cracks and rock porosity, originating from an old recharge without tritium and nitrate, and (b) a rapid recharge, through fractures and karstic features, where present, resulting in a present day recharge rich in tritium and very rich in nitrate. In the MSLA the first component is largely dominant. Thus aquifer recharge is heterogeneous and similar to recharge in chalk aquifers elsewhere.

Up to now, potentiometric maps and pumping tests, as well as hydrodynamic modelling of the MSLA, have been applied in studying the dynamics of the main

source of groundwater supplying potable water in Malta. However, the reliability of the model outputs has been constrained by a series of unknowns, namely: (a) the natural discharge into the sea cannot be accurately assessed from field evidence; (b) salinization is still observed despite the strict control and the conditions of abstraction, mainly from galleries above mean sea level; (c) most of the aquifer is polluted by nitrates, even where it is protected by an impermeable cover.

Isotope and chemical natural tracing is a well known methodology and is now being applied in Malta in order to answer these questions. These initial data show that very slow infiltration dominates groundwater recharge, while a rapid component may locally inject, during present times, a small amount of highly polluted water. Therefore as one expects in a true karst environment, karst plays a limited role in the recharge process, contrary to what has been hitherto believed. If karst features developed more, groundwater would then “reside” for shorter intervals in the MSLA and would be subjected to more frequent renewal. Our results show that this is not the case.

Additional data are required to comprehensively identify all the recharge and discharge conditions of the aquifers. New information on the geochemistry of groundwater shall lead to better understanding of the dynamics of groundwater flow. Consequently, the results of these studies warrant a revision of national management plans for the sustainable management of groundwater resources in Malta, where new strategies will be defined on the basis of improved hydrogeological data.

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