Shallow transient electromagnetic method application for groundwater exploration: case study from Greece

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SUMMARY

The transient electromagnetic method (TEM) survey was carried out within one of the private house area to allocate the fresh water reservoirs in Greece.

There are two challenges that make the problem complex. The first is noisy settings for geophysical survey: populated area with power lines, pipes, houses etc. The second challenge is uncertainties with water-bearing reservoirs.

According to geological settings and water-bearing reservoirs location, geophysical survey had to maintain penetration depth up to 250-300 m. For this task DC (direct current) methods are not applicable whereas induction electromagnetic sounding like Transient electromagnetic method (TEM) in the near field zone can show superior results. Therefore TEM survey was carried out.

To ensure the high quality of TEM data the special algorithms of electromagnetic noise attenuation were applied.

From TEM results it was found, that at a depth of about 180–280 m in the southeastern part of the study area, one can expect the presence of fresh water, and the resistance values are 80 Ω·m.

Key words: transient electromagnetic method, resistivity, limestone, groundwater.

INTRODUCTION

Well known that Greece is dependent on groundwater resources for its water supply. The main aquifers are within carbonate rocks (karstic aquifers) and coarse grained Neogene and Quaternary deposits (porous aquifers).

Water needs are mainly covered by groundwater abstracted from the aquifers via numerous wells and boreholes. A negative water balance is established in the coastal aquifer systems triggering sea water intrusion which has negative consequences in the socioeconomic development of these areas. Many aquifer systems are reported to be affected by quality deterioration (salinisation and nitrate pollution) due to irrational management (Daskalaki, 2006).

The transient electromagnetic method (TEM) survey was carried out within one of the private house area to allocate the fresh water reservoirs. There are two challenges that make the problem complex. The first is noisy settings for geophysical survey: populated area with power lines, pipes, houses etc. The second challenge is uncertainties with water-bearing reservoirs. In the upper part of the section there are brackish water reservoirs, much deeper (up to 150-200m?) there can be fresh water reservoirs. However, lack of prior information on water properties and its depth (due to poor information volume on drilled wells) makes the geological task difficult to solve.

SURVEY AREA OVERVIEW

The Porto-Heli region belongs to the southern end of the Southern Argolid peninsula which is bordered to the north By a large mountainous region which includes the mountains of Dhidima (1,113 m) and Adheres (588 m) (Poulos S.E., 2008).

The southern Argolic peninsula belongs to the Pelagonian isotopic zone. The Dhidhima Range consists of Triassic-lower Jurassic limestones, dolomites and marbles (tj), whilst the Adheres Range is formed by flysch formations (fg) (mainly shales and sandstones). The southernmost of the peninsula, including the Porto-Heli region, covered by the so called Peloponnesian conglomerate of Plio-Pleistocene age (pq) (Poulos S.E., 2008).

The complex stratigraphy and the tectonic activity of the area have given the Argolis peninsula a substantial lithological heterogeneity in horizontal and vertical directions, which has led to the formation of independent aquifer systems and the appearance of a number of individual springs mainly of small discharge allocated in carbonate formations, as well as in less permeable lithologies, such as the ophiolitic mélange and the flysch sediments (Matiatos, 2010). The latter is evidenced by the presence of springs as well as of numerous wells and boreholes. In situ geological and hydrogeological observations have revealed that the majority of the water bearing geological formations appearing in the peninsula show primary or/ and secondary porosity.

Therefore, the groundwater systems occurring in them are expected to have diffuse flow through small fractures and the granular matrix of the rock, where the water seeps slowly through the aquifers.

Hence, prospective for water horizons are:

1. Aquifers in which flow is mainly intergranular (alluvial fans, debris cones, loose sediments of silts, sands and pebbles): local productive aquifers of small thickness or extensive but moderately productive aquifers.
2. Fissured aquifers with secondary porosity: extensive aquifers with high productivity (limestones of Triassic-Eocene age) or local productive aquifers of small thickness or extensive but moderately productive aquifers (limestones of limited extent inside the flysch formations and the tectonic mélange Pelagic limestones of Mesozoic age).

TEM TECHNIQUE

According to geological settings and water-bearing reservoirs location, geophysical survey had to maintain penetration depth up to 250-300 m. For this task DC (direct current) methods are not applicable whereas induction electromagnetic sounding like TEM can show superior results.

Transient electromagnetic surveys have been used broadly in Russia and worldwide for engineering geology, groundwater prospecting, and other near-surface applications (Bucharsky et al., 1986; Plotnikov and Kozhevnikov, 2004; Agafonov et al., 2013; Ranieri et al., 2005; Shaaban et al., 2016, etc.), as well as for petroleum and mineral exploration (Mandelbaum et al., 1983; Korolkov, 1987; McNeill, 1980). Voltage decay patterns are highly sensitive to the presence of conductors associated with ore bodies, water saturation, clay, etc. Another advantage of the method is that it does not need galvanic grounding and works in any climate and terrain.

The resolution of shallow transient electromagnetic (TEM) data has improved greatly in two recent decades due to breakthrough in micro-electronics providing advanced facilities for data acquisition and processing (nanosecond sampling rates, high-resolution ADC, etc.).

Rocks of the same lithology, especially sediments, may have different resistivities depending on physical state, burial depth, structure, temperature, etc. TEM surveys provide differentiation of rocks according to their electrical properties.

Transient electromagnetic method in the near field zone is a controlled-source induction resistivity survey method. The sources and receivers of the electromagnetic (EM) field are lines or high-tech loop-loop or central-loop (in-loop) configurations which require no ground and can run in any season. In practice the loop configuration is commonly combined, with two receivers laid outside (Q-q) and inside (Qq) a single transmitter loop (Fig. 1).

Figure 1. TEM layout at the survey area

Observation grid. TEM soundings performed at high density within the housing area with flexible spacing (approx. 40m) with FastSnap equipment (Fig. 2).

Transmitter loop (Tx) size was 50×50 m (2 turns) and 100×100 m (1turn), 55×125 m, and 10×10 m for receiver loop (Rx). Current strength in Tx varied from 0.1 to 29 Amp to study the section from 10 to 400 m.

Figure 2. TEM equipment: FastSnap receiver (left) and transmitter (right)

TEM data processing and interpretation carried out with SGS-TEM software (TEM-Processing and Model 3).

EM NOISE ATTENUATION

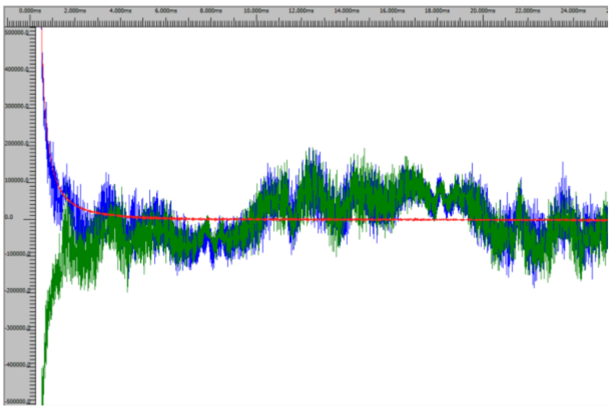


Figure 3. The initial EMF decay (negative and positive polarity are green and blue graphs, respectively) complicated by a 50 Hz power lines interference and the result of digital interference processing (red graph).

TEM soundings were performed in the settings of a high level of anthropogenic interference of 50 Hz due to the 0.4 kV power line passing through the site. The FastSnap equipment provides a measurement of the TEM signal with an arithmetic sampling frequency (full waveform recording) and the preservation of all recorded EMF decays in the database for subsequent digital processing.

Typical EMF decays complicated by 50 Hz interference are shown in Fig. 3 (blue and green graphs). Due to the use of digital filtering algorithms and decomposition of interference from the recorded data, it was possible to obtain the final TEM curves of good quality, providing the necessary investigation depth. An example of a processed EMF decay after a 50 Hz interference attenuation is shown in Fig. 3 (red graph).

TEM SURVEY RESULTS

Geophysical surveys were performed within the territory of Porto Cheli, Greece, which built-up with houses and utility structures, with high electromagnetic noise

From TEM data inversion the geoelectrical model of the upper part of the section was built up to 400m which contains fresh, brackish and brine water.

The high contrast of rocks electric properties is evident from geoelectric section (Fig. 4).

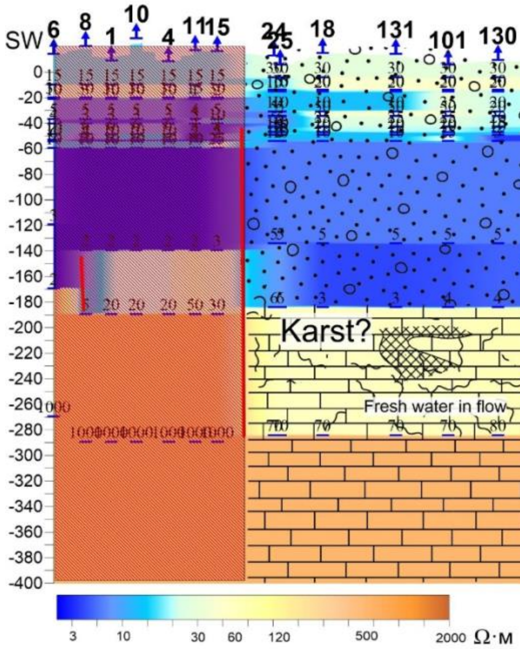


Figure 4. TEM geoelectric section

The upper part of the section to the depth of 160 – 190 m associated with neogene sediments (Pl- Upper Miocene to Lower Pliocene marine deposits). Resistivity varies from 1 to 30 Ω·m.

Intervals with resistivity 1 – 3 Ω·m apparently related to alluvial sediments saturated with sea water (Fig. 5). Due to the high salinity of water up to 5 g/l, resistivity of sediments on the depth from 100 to 100 m is significantly lower compared to host rock. These geoelectrical patterns are evident form geoelectrical section.

According to the TEM data, a high resistivity layer (from 20–80 to 1000 Ω·m) with a thickness of about 220 m located below. High values of resistivity indicate limestones lying here, which corresponds to the geological model of survey area structure. A wide range of resistivity values is associated with the presence in the section of dense limestone (over 100 Ω·m) and karsted limestone, characterized by resistivity below 100 Ω·m.

As is known, karst systems in Greece are valuable freshwater resources. So, in the area of the well one can see that the inflow of fresh water is obtained from a geoelectric layer with a resistivity of 80 Ω·m (180 - 280 m), which indicates the possible presence of karst limestone here (Fig. 4).

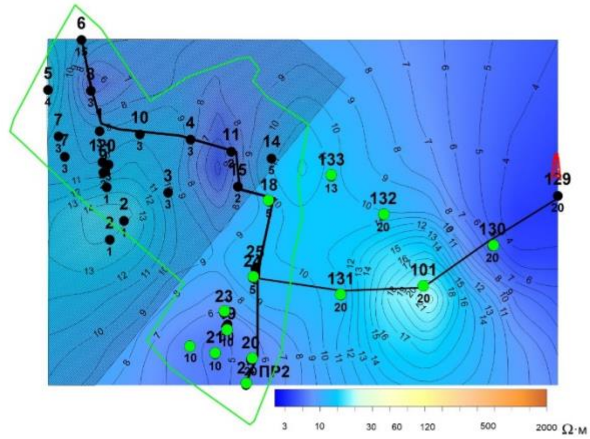
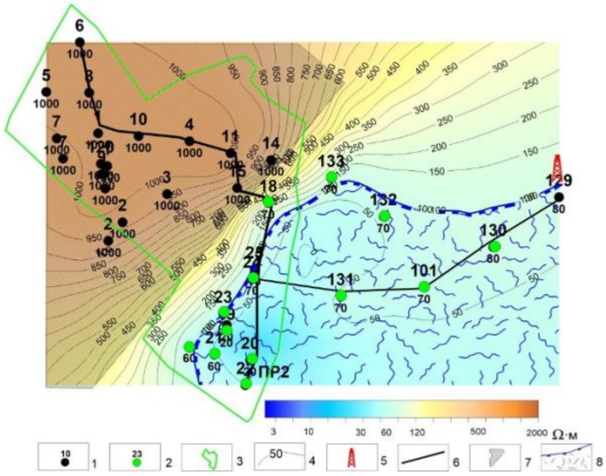


Figure 5. TEM resistivity map to the depth of 40m

On the resistivity map at a depth of 250 m in the area of the well with fresh water inflow, a zone with a resistivity of 50–100 Ω·m is marked, which is pulled in the direction of the study site. Thus, taking into account similar conditions of the well site (with fresh water inflow), a similar zone in the area of the study area may indicate similarity of the cuts and, accordingly, similar hydrogeological conditions (Fig. 6).



Legend: 1 — TEM Rx points complicated by infrastructure, 2 — TEM high-quality Rx points; 3 – survey area contour; 4 - hydrogeological wells, infrastructure facilities; 5 - well with fresh water inflow; 6 - profile lines; 7 - section with poor-quality TEM data (influence of infrastructure); 8 - predicted area of fresh groundwater in karst limestone.

Figure 5. TEM resistivity map to the depth of 250m

CONCLUSIONS

According to the TEM results, it was revealed that at a depth of about 180–280 m within the study area, one can expect the presence of fresh water, by analogy with the neighboring area, where at a depth of ≈250 m fresh water is obtained, and the resistance values are 80 Ω·m.

Fig. 6 shows that the proposed zone of development of fresh groundwater at a depth of 180 to 280 m is located in the southeastern part of the study area.

It should be noted that, subject to the availability of fresh water within the contour of the survey area, it is necessary to take into account the fact that the presence in the adjacent area of an already drilled (if applicable) hydrogeological well may affect the flow rate of fresh water extracted from the same interval of depth. The probability of decreasing flow rates may increase in the case of lenticular distribution of the reservoir horizon in limestone, since its development zone is not contoured.

It should also be noted that the assessment of the balance of groundwater in the karst area is a difficult task and often requires additional studies. Systematic research and a thorough understanding of the hydrological regime of such aquifers is important for ensuring successful groundwater resource management practices.

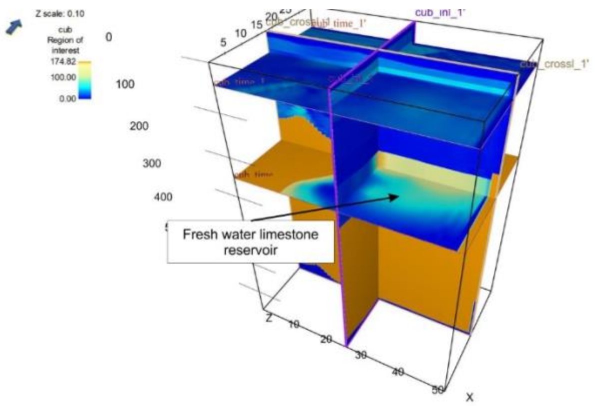


Figure 6. 3D TEM resistivity model

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