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Mapping of Deltaic Aquifers with the Combined Application of DC and TEM Soundings

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Summary

The current study aims to clarify the hydrogeological regime of the deltaic valley of Pinios river (Thessaly, Greece). Its purpose is to map the existing aquifers below the deltaic plain, but also to assess the quality of their water (detect possible seawater intrusion), through the combined application of VES and TEM soundings. The results of the geophysical data processing revealed that the shallow (phreatic) aquifer is not detected throughout the entire deltaic plain, but only in the central and northern parts of the region, with thickness of 5-10 meters. Additionally, a deeper aquifer has been detected, with a maximum thickness equal to 100 meters. The interpretation of the geophysical soundings indicated that great part of the deeper aquifer has been affected by a saline intrusion that has also been noticed by hydrochemical data. Based on the fact that Pinios deltaic plain is a highly productive agricultural area, the irrigation system has to be reevaluated in order to constrain the extension of the seawater intrusion.

Introduction

The deltaic plain of Pinios River lies in the area of central Greece. It has a significant ecological importance, given the fact that it is classified as "Special Protection Area" of the NATURA 2000 network (GR1420015) and a CORINE biotope (A00020006). It includes riparian forests, an estuary with riparian woodland, marshes, small freshwater lakes, sand dunes and coastal zones. Moreover, it is characterized by rich fresh surface water availability and by the extensive agricultural cultivation, establishing it as one of the most productive agricultural lands (kiwi, olive trees, corn, sunflower, cotton plantations) of the broader area. Irrigational water is obtained by groundwater and river water extraction, with the first one mostly extracted from shallow boreholes with suction pumps.

The present study aims to investigate the extent and quality of the deltaic aquifers, through the combined application of Vertical Electrical Soundings (VES) and Transient Electromagnetic Soundings (TEM). These methods have been successfully used in the past by other researchers, especially for mapping coastal aquifers and seawater intrusion (Albouy *et al*., 2001; Yang *et al.*, 1999).

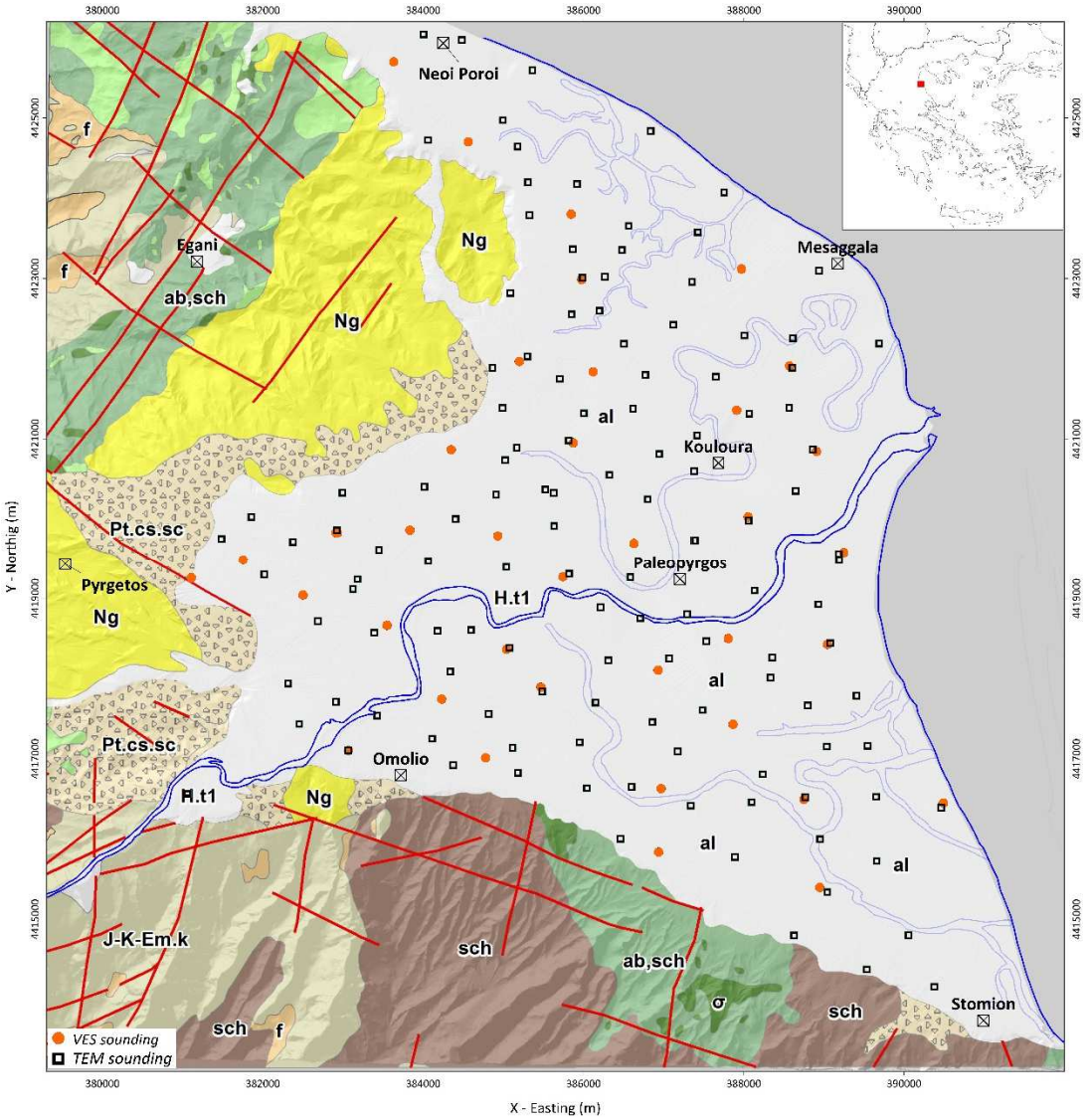

Figure 1. *Geological and tectonic map along with the locations of the geoelectrical soundings (VES) and Transient Electromagnetic Soundings (TEM).*
H.t1*: Unconsolidated materials on torrent and terraces,* ***al****: Alluvial deposits,* ***Pt.cs.sc****.: Old talus cones, scree and materials of torrential terraces,* ***Ng****: Terrestrial and lacustrine Neogene deposits,* ***J-K-Em.k****: Crystalline limestones,* ***Sch****: Blues schists, gneiss schists and prasinites,* ***Ks.mr****: Upper Cretaceous marbles,* ***ab.sch****: Metamorphic basic ophiolithic rocks*

Geological and hydrogeological setting

The fluvial deposits cover the largest part of the delta plain, whilst the coastal deposits crop out along the entire coastal zone. The remnants of a Pleistocene alluvial fan is observed in the western part of the delta plain and lies uncomfortably on Neogene formations comprised of sandstones, conglomerates and terra rossa. The alpine basement outcrops are found only at the southern and northern margins of the delta plain and include various lithologies such as crystalline limestones and metamorphic flysch (*Ossa-Olympos unit*), blue schists, gneisses and marbles (*Ambelakia unit*), metamorphic basic ophiolitic rocks and marbles (*Pelagonian unit*). Based on Vassilakis *et al.* (2014) the Neogene formations have undergone intense tectonic deformation resulting in several block rotations reaching the values of 10-30^{o}, towards south. The NW dipping normal fault zone located south of Omolio village strikes WSW-ENE and seems to play a significant role in the rotation of the Neogene formations. The majority of the beach zone granulometry, is characterized as sand and gravelly sand (Lazogiannis *et al.,* 2014)

Taking into account the geological-geoelectrical sections that have been constructed (Alexopoulos *et al.*, 2014a), it seems that the Neogene formations, with alternations of sands, marls and conglomerates occupy almost the entire space of the subsurface deltaic field, below the Holocene deposits. Additionally, the alpine formations of Ossa (the southern part of the field research), have been identified only in the soundings near the margins, with a gentle inclination below the post-alpine sediments, for the depths of investigation up to 200-250 meters.

Based on Matiatos *et al.,*(2018), the shallow aquifer, besides the precipitation, is also recharged through the debris cones and screes of Pleistocene age at the inland limit of deltaic plain (where the Pinios River exits the Tempi valley and enters the deltaic plain) but also by lateral less permeable formations, such as the Neogene sediments. Matiatos *et al*. (2014) also indicated hydraulic interaction between the river and the aquifer, especially in the central part of the plain, depending on location, season and groundwater level fluctuation.

Methodology

In the context of the geophysical research in the region, a grid of 41 Vertical Electrical Soundings (VES) with *Schlumberger* array was carried out during the summer months (Fig. 1), investigating the resistivity distribution. The maximum current electrode spacing (AB) was 1400 m, achieving an investigation depth of almost 200-250 meters. The field measurements were carried out with an ABEM Terrameter System. The geoelectrical data were processed by applying the automatic method of Zohdy (1989), composing a “multilayer” model. Furthermore, the Interpex commercial software package IX1D was used to produce the “layered” model.

A dense grid of 127 TEM soundings was also carried out covering the entire basin area (Fig. 1). The TEM method is highly sensitive to low-resistivity layers since a larger amount of the current flows in these layers. All the soundings were performed with the ABEM WalkTEM Time Domain Ground EM system. The field configuration for data acquisition was comprised of a 40m x 40m square transmitter loop (Tx-loop), with two in-loop antennas (the 10m x 10m RC-200 and the 0.5m x 0.5m RC-5). The RC-5 receiver is optimized for high resolution, shallow soundings, while the RC-200 is suitable for deeper soundings. With this field setup, an investigation depth of almost 200 meters was achieved. The data processing and inversion were carried out with ViewTEM software.

Discussion & Conclusions

The results of the geophysical data processing indicate that the phreatic aquifer is not detected throughout the entire deltaic plain, but extends mainly in the alluvium deposits of the central and northern parts (Fig. 2), with a thickness of 5-10 meters and fresh water, based on the resistivity values (10-17 Ohm.m). Taking into account the interpretation results and the lithological structure of the coastal area, it seems that there is an impermeable formation between the coast and the eastern boarder of the aquifer, which naturally blocks the sea intrusion. The majority of the investigated sites revealed

that the hosting formation's thickness is limited up to 10 meters, since the underlying geoelectrical formation (20-40 Ohm.m) is believed to be the impermeable clay-marls formation, detected with a medium thickness of 30-35 meters.

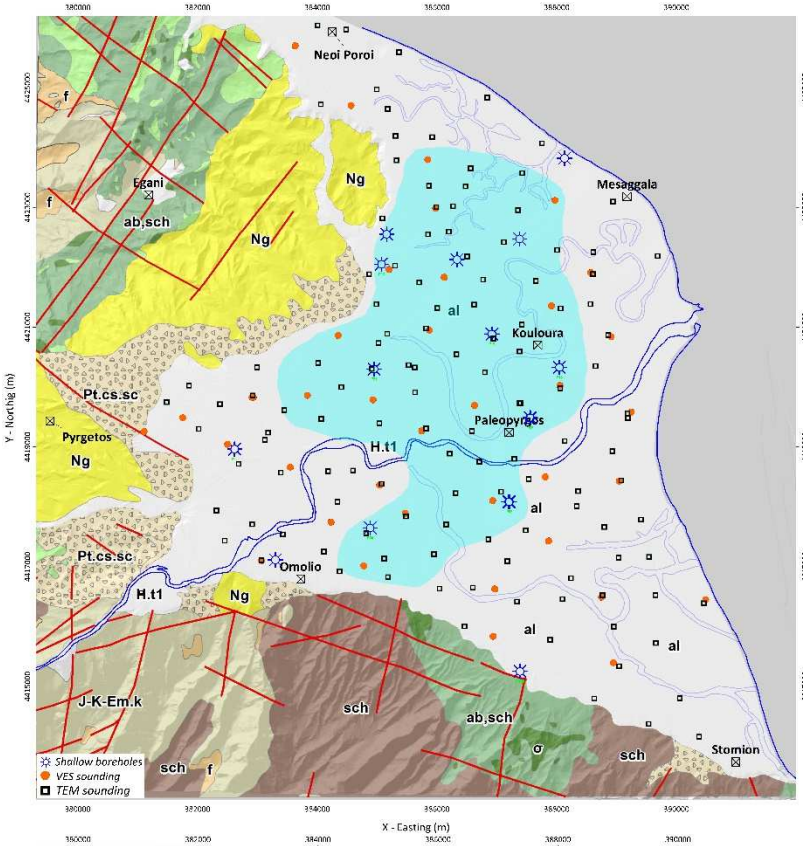

Figure 2. *The extension of the shallow aquifer, based on the geophysical interpretation*

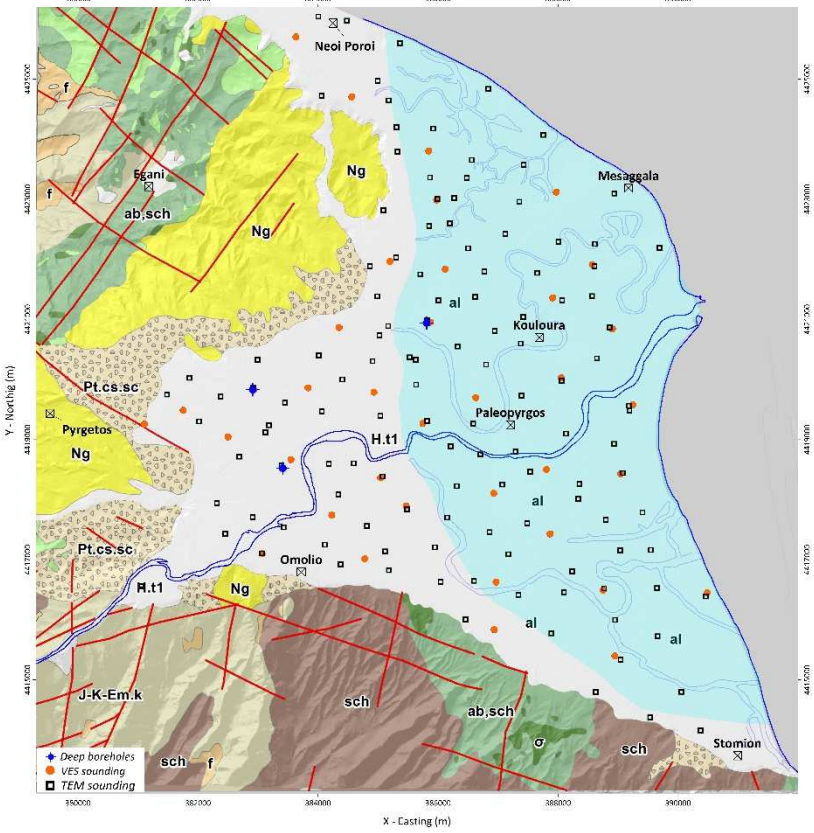

Figure 3. *The extension of the seawater intrusion in the deeper aquifer, based on the geophysical interpretation*

On the other hand, a deeper aquifer has also been investigated under the biggest part of the deltaic plain, with a maximum thickness equal to 100 meters, verified also by deep boreholes (Manakos, 2009). Low resistivity values (<5 Ohm.m) characterizing this deeper aquifer have been noticed at many soundings, indicating a possible saline intrusion (Fig. 3) that covers more than half of the deltaic valley. This information seems to be consistent with hydrochemical data (Alexopoulos *et al.*, 2014b; Matiatos *et al.*, 2018) that also indicate a seawater intrusion. Based on the same literature, this intrusion seems to be controlled by the hydraulic head of the groundwater and the sedimentological composition of the dune system covering the coastal zone.

The identification of both aquifers' geometry, the assessment of their water storage quality and the mapping of the seawater intrusion are very important for the local agriculture. Based on this information the local community should re-consider their irrigation system. The over-pumping has to be avoided in order to constrain the extension of the seawater intrusion and the pollution of the local aquifers.

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