

OVEREXPLOITATION OF GROUNDWATER RESOURCES IN THE COASTAL AQUIFER SYSTEM OF ARGOLIS

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Abstract

Intense abstraction of groundwater resources in the coastal aquifer system of Argolis is investigated since the late 1950's. The increasing water demands due to the agricultural development of the area (mainly citrus trees) during the last years, in combination with the touristic growth, has led to the overexploitation of groundwater resources of the coastal aquifer system of Argolis. This paper presents the piezometric conditions in the plain of Argos during the period between 1986 and 2014, analysing the fluctuations of groundwater levels and highlighting the problem of seawater intrusion in the study area. In October 2014, measurements were made in app. 160 wells and drills which are located within the boundaries of the granular aquifer of the study area. Selected piezometric maps are presented, which demonstrate the problem of overexploitation of groundwater in the plain of Argos.

Keywords: Coastal aquifer, seawater intrusion, overexploitation, plain of Argos.

Περίληψη

Η υφαλμύρωση του Αργολικού πεδίου αποτελεί σημαντικό πρόβλημα, το οποίο άρχισε να γίνεται αισθητό στις αρχές της δεκαετίας του 1960. Η εντατική γεωργία με την αλματώδη ανάπτυξη των αρδευόμενων καλλιεργειών και ιδιαίτερα των εσπεριδοειδών σε συνδυασμό με την ανάπτυξη του τουρισμού οδήγησε στην υπερεκμετάλλευση των υπόγειων νερών με καταστροφικές συνέπειες για τα υδροφόρα στρώματα της περιοχής. Η παρούσα εργασία παρουσιάζει την διερεύνηση της πιεζομετρικής κατάστασης των εκμεταλλεζόμενων υδροφόρων στρωμάτων στο Αργολικό πεδίο από το 1986 έως το 2014, θέλοντας έτσι να τονίσει τις διακυμάνσεις στη στάθμη των υπόγειων νερών της περιοχής και να προβάλει το πρόβλημα της θαλάσσιας διείσδυσης στην περιοχή μελέτης. Για την διερεύνηση της πιεζομετρίας του υδροφορέα πραγματοποιήθηκαν μετρήσεις στάθμης Υ.Ν. το μήνα Οκτώβριο 2014 σε περίπου 160 γεωτρήσεις, η θέση των οποίων εντοπίζεται μέσα στα όρια του κοκκώδους υδροφορέα. Παρουσιάζονται και σχολιάζονται χάρτες πιεζομετρικών καμπυλών που σκιαγραφούν την εξέλιξη του φαινομένου και καταδεικνύουν με μεγάλη σαφήνεια το πρόβλημα της υπεράντλησης των γεωτρήσεων του Αργολικού κάμπου. Τέλος παρατίθενται συμπεράσματα που προκύπτουν ύστερα από την ανάλυση των πιεζομετρικών χαρτών χωροχρονικά από το 1986 έως το 2014.

Λέξεις κλειδιά: Παράκτιος υδροφορέας, υφαλμύριση, υπερεκμετάλλευση, Αργολικό πεδίο.

1. Introduction

Coastal aquifer systems are thought to be sensitive water bodies that are highly susceptible of groundwater contamination due to seawater encroachment towards the mainland. This problem is even

more pronounced in the case of coastal Mediterranean aquifers where the climatic conditions in combination with the observed global changes, have resulted in increased water demands for several uses (mainly agricultural). Overexploitation of groundwater resources in such systems is a rather typical problem for the Circum-Mediterranean, as recorded in many studies (Ahmed *et al.*, 2013; Astaras and Oikonomidis, 2006; FAO, 1997; Garing *et al.*, 2013; Giannouloupoulos, 2000; Melloul and Goldenberg, 1997; Polemio *et al.*, 2009; Psychoyou *et al.*, 2006; Stamatis *et al.*, 2006; Trabelsi *et al.*, 2012; Recinos *et al.*, 2015; Gkiougkis *et al.*, 2015; Pedreira *et al.*, 2015; Pliakas *et al.*, 2015).

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2. Description of the study area

The study area is located within the plain of Argolis, presenting a typical Mediterranean coastal setting in terms of its climatic, geologic and hydrogeologic conditions as well as the associated groundwater abstraction practices together with the land-use patterns. The study area (Figure 1) is confined within the extent of the alluvial aquifers of Argolis, while the agricultural area within it comes up to app. 180km². It is located NE of Argos, extending to the SE of Nafplion. The morphologic relief is rather mild, while the main crop type is citrus trees, which are cultivated almost exclusively within the entire area of investigation. The climate is typical Mediterranean with warm and dry summers.

2.1. Geological setting

Argolis plain is surrounded by a mountainous zone that mainly consists of limestone and flysch, as well as of Pleio-Pleistocene sediments within the N and NW boundaries (Figure 2). The metamorphic basement of central Peloponnese, outcrops within a confined area of extent at the western side of Argolis plain (Giannouloupoulos, 2000).

The lithologic structure of Argolis plain mainly includes permeable carbonate formations, impermeable formations (flysch, schists) as well as formations of variable permeability such as Neogene and quaternary deposits.



Figure 1 - Geographical location of the study area (Source: Google maps©2015).

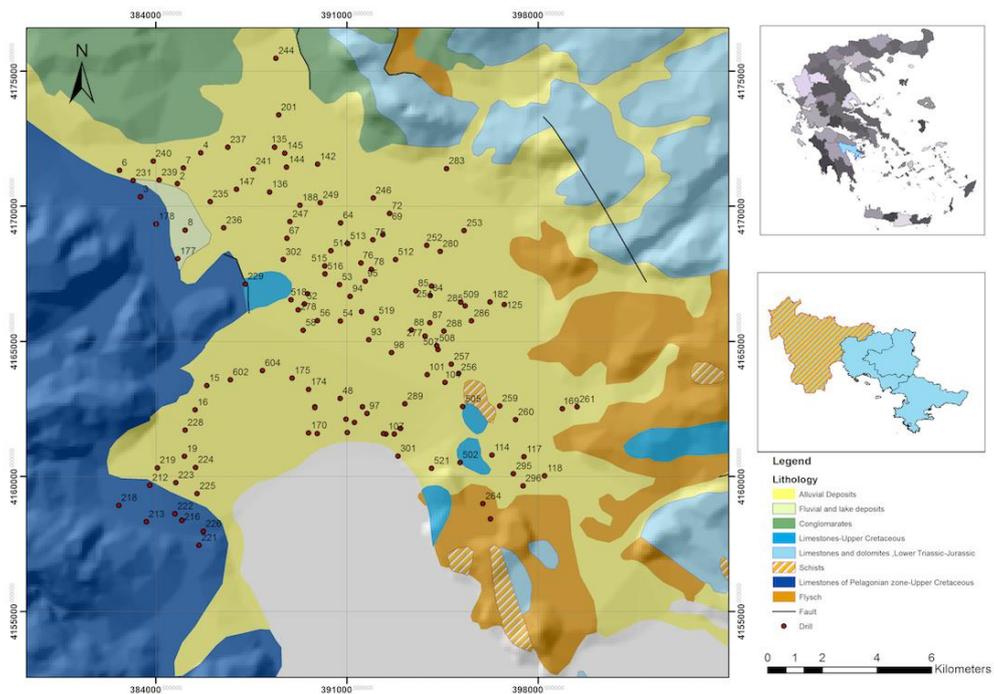


Figure 2 - Geological map of the study area with the monitoring network.

2.2. Hydrogeological conditions

Argolis plain mainly contains four (4) hydrogeological units, which are categorized according to the aquifer type that they involve. More specifically, the aquifers in question involve: the karstic system of western Argolis; the granular aquifer that are developed within the coastal part of Argolis (main research area); the karstic system of M. Arachnaeo; and the karstified/fractured aquifer unit of Tracheia-Ermionida. Apart from the karstic system of western Argolis (which has a significant groundwater resources potential of high quality) the latter three units are mainly associated with high concentrations of nitrate and chloride ions due to intense agricultural activities and seawater intrusion.

The main area of investigation involves the granular aquifer system that is developed within the central part of Argolis plain, containing sediments of variable grain size (Giannouloupoulos, 2000).

- The phreatic aquifer, is mainly composed of fine-grained sands with varying clay layering, is developed within a zone of 200-300m towards the mainland. The maximum depth of the coastal aquifer part, reaches 7-8m, while it overlies the clayey covering layer of the area.
- The upper aquifer layer is developed from the bottom of this clayey cover down to app. 30m, consisting of gravels, sands, pebbles and limestone aggregates.
- The second aquifer layer is developed down to a depth of 50-70m, consisting mainly of gravels, sands and pebbles, while
- The third aquifer layer consists of conglomerates that also contain sandstone pebbles, clays and marles.

The piezometric conditions of the study area were investigated through a wide measuring campaign that took place in October 2014, from app. 160 measuring points (mainly groundwater wells and boreholes) which are evenly distributed throughout the entire study area.

The piezometric map of Figure 3, shows a deep cone of depression that reaches -27m (a.m.s.l.) that is located within the upstream area of the investigated aquifer, while the water table is rather high within the lateral boundaries of the aquifer. The latter observation is attributed to the lateral recharge of groundwater from the surrounding karstic aquifer system of the study area. The hydraulic gradient of the piezometric surface is rather inverted (from the seashore to the mainland), which is an evidence of active seawater intrusion.

For the analysis of the water table fluctuations during the period 1986-2014, a series of piezometric profile cross-sections were designed along axes AA', BB' and CC', as shown in Figures 4,5 and 6.

Figure 4, shows that the lowest cone of depression was formed in 1990, while the highest water table was recorded during the measurements of 2000 and 2010. During the period between these aforementioned values, the piezometric surface fluctuates between -40m and -10m.

Figure 5 and 6, shows similar conclusions, where the cone of depression fluctuates between -5m and -35m for the years 2000 & 2010 and 1990 respectively. The same figures (5 and 6), show that the piezometric lines within the coastal part, tend to coincide throughout all the investigation period due to the immediate encroachment of seawater into the aquifer. On the contrary, the contour line at the lateral boundaries of the aquifer, follow the general fluctuation pattern of every respective year.

Figure 7, shows the spatial distribution of chloride ions, collected from 60 groundwater wells and boreholes that generally follows the pattern of the piezometric surface of the alluvial aquifer. Chloride ions concentration ranges between app. 100mg/L and 1800mg/L at their peak parts. Figure 8, shows that chloride ions are dominant for the groundwater samples that are adjacent to the coastline, while the rest of the samples are found within the mixing zone.

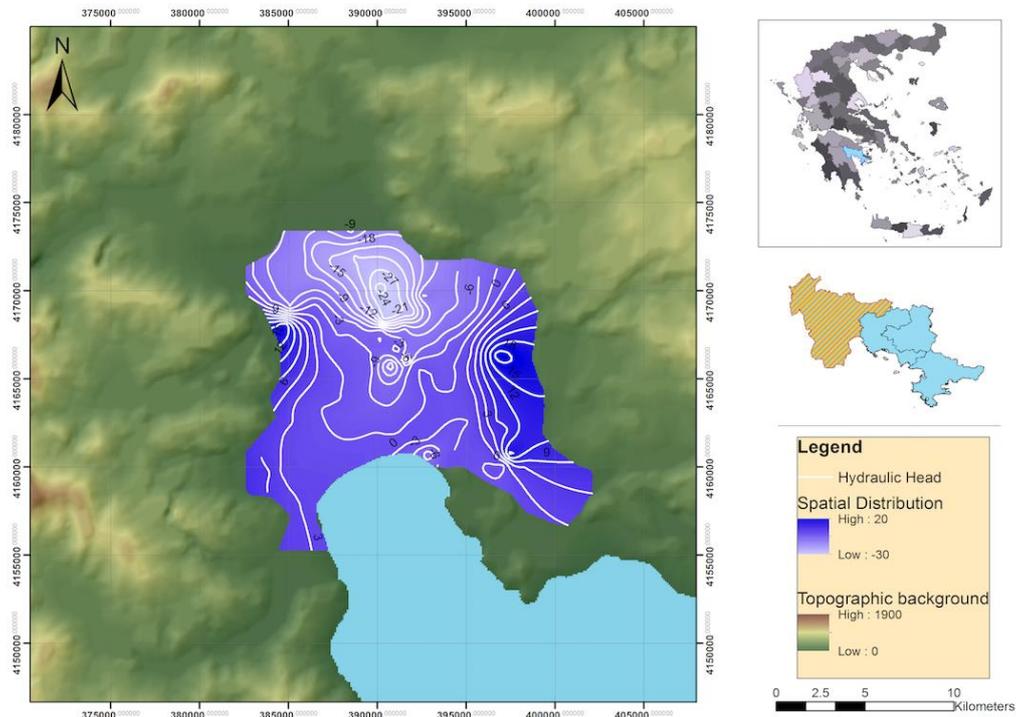


Figure 3 - Piezometric map of the investigate aquifer (October 2014).

Cross Section AA'

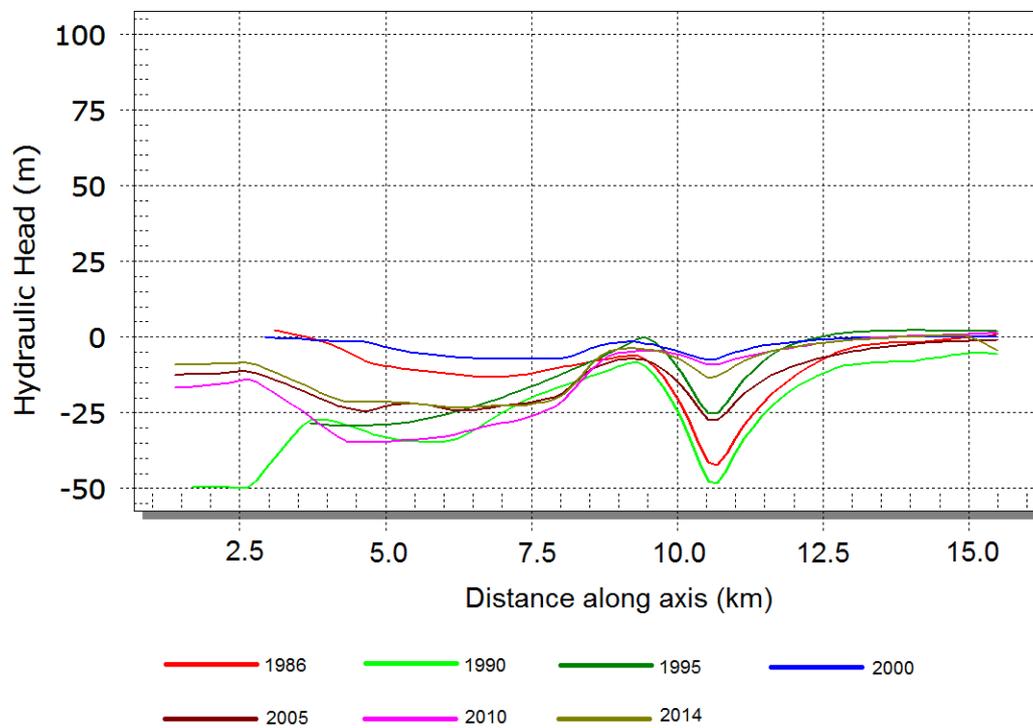


Figure 4 - Piezometric profile fluctuation (along axis AA') during the period 1986-2014.

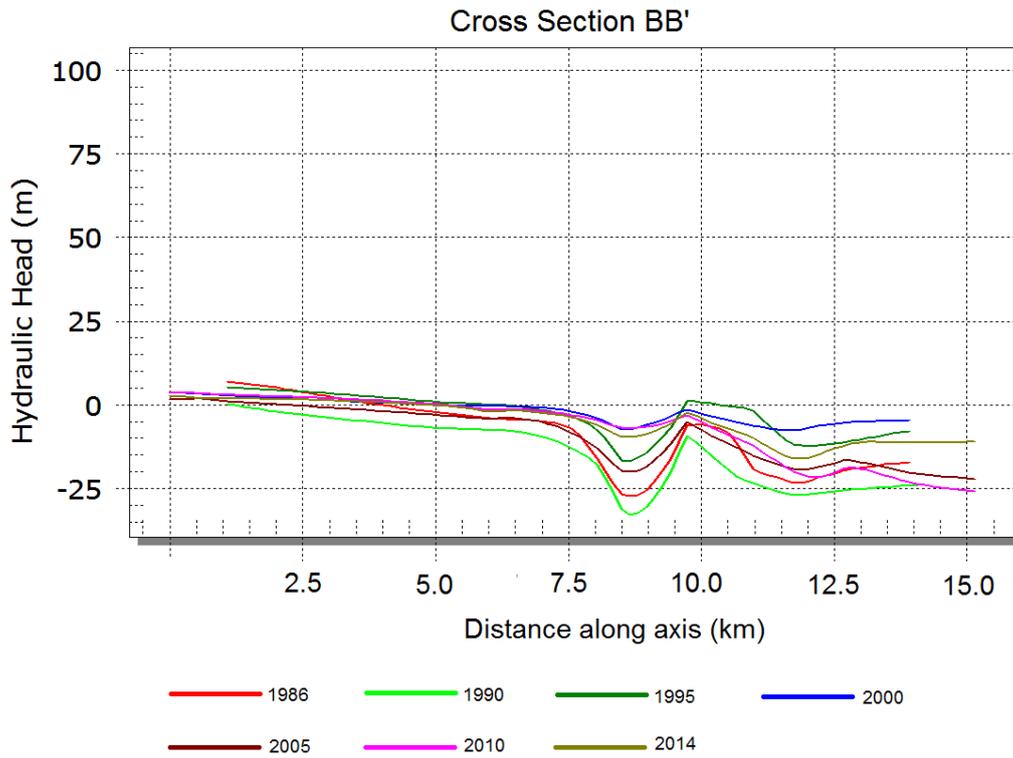


Figure 5 - Piezometric profile fluctuation (along axis BB') during the period 1986-2014.

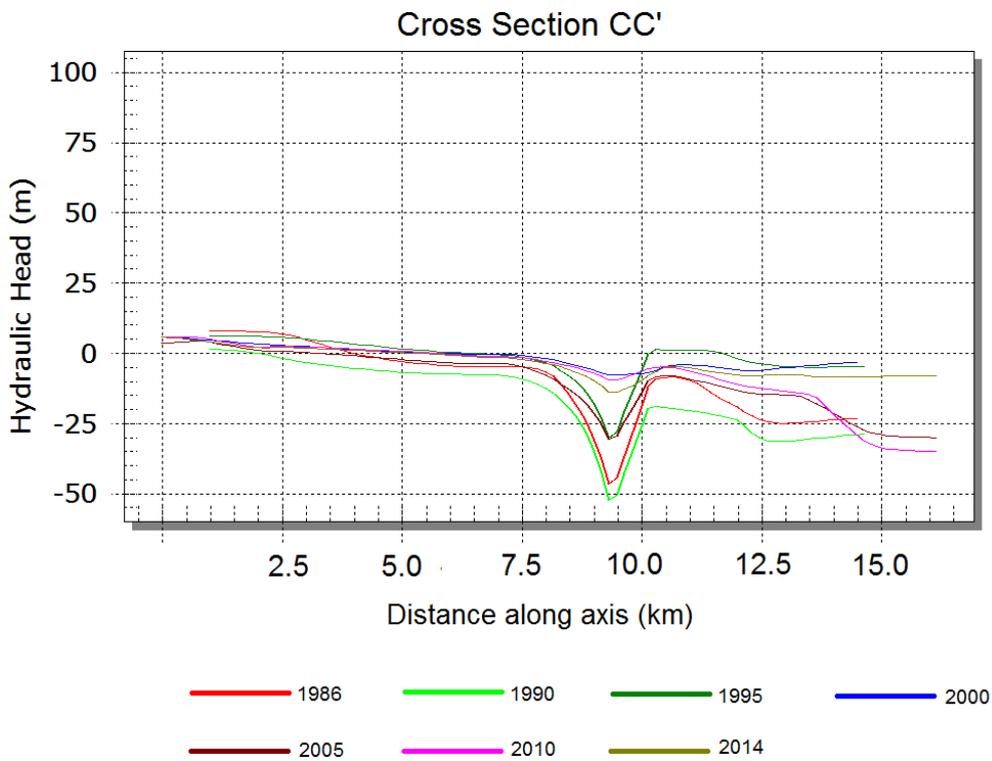


Figure 6 - Piezometric profile fluctuation (along axis CC') during the period 1986-2014.

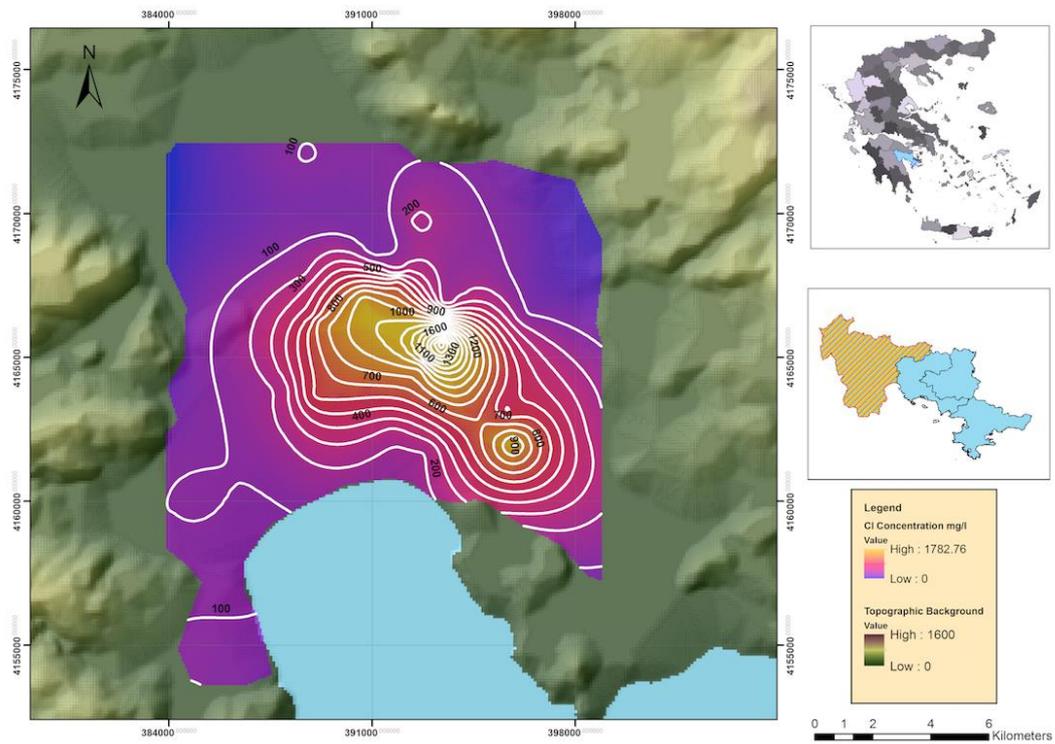


Figure 7 - Spatial distribution of chloride ions (October 2014).

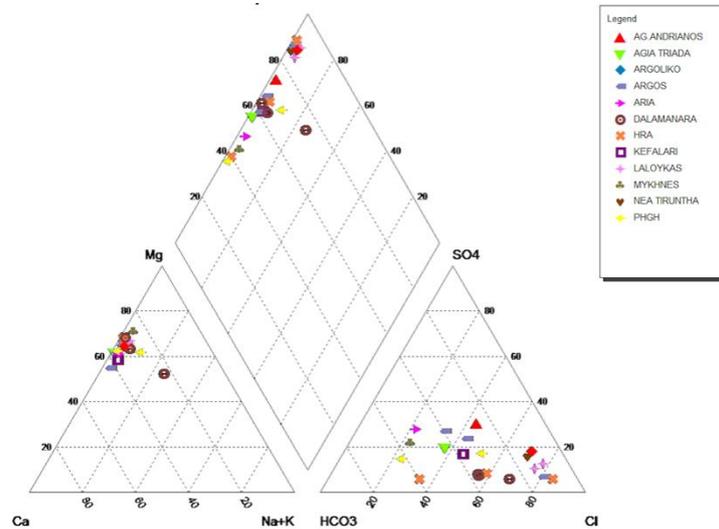


Figure 8 - Piper diagram of 60 groundwater samples from the study area (October 2014).

3. Conclusions

The main conclusions that are drawn from this investigation, show that the groundwater potential of the Argolis aquifer system changes on both seasonal and annual basis. The groundwater table fluctuations mainly depend on the amount of water abstractions that are used for irrigation purposes as well as the lateral recharges from the surrounding limestone aquifers within the area.

Since the beginning of the study period in 1986, the aquifer system shows distinct recharge axes that are located at the boundary conditions of the alluvial system, while the constant depression of the water table, gives rise to seawater intrusion conditions during the entire investigation period (1986-2014). Groundwater recharge also takes place as percolating waters from the ephemeral streams (at both the western and eastern boundaries) of the area infiltrate down to the water table.

More specifically:

Since 1986, almost 50% of the entire study area shows negative (below m.s.l.) piezometric conditions that are formed from pumping rates which exceed safe yields.

- The lowest water tables have recorded during 1990, when the water table reached a depth of 40m below m.s.l.
- Piezometric conditions are shown slightly improved in 1995, however most of the northern upstream part shows negative water tables that reaches -28m a.m.s.l.
- During 2000, the area that shows negative piezometric contour lines is significantly shrunk, confined within the central part of the investigated aquifer. Especially within the western and eastern boundaries, the recorded water tables are found more than +10m a.m.s.l.
- During October of 2010, the hydrogeological conditions are distinctively improved, in comparison to 2005. This is mainly attributed to the application of Managed Aquifer Recharge (MAR), where 7.3×10^6 m³ of groundwater from the springs of Kefalari, that took place during the wet period of 2009.

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