Δελτίο της Ελληνικής Γεωλογικής Εταιρίας, τομ. XLVII , 2013
Πρακτικά 13ου Διεθνούς Συνεδρίου, Χανιά, Σεπτ. 2013

Bulletin of the Geological Society of Greece, vol. XLVII 2013
Proceedings of the 13th International Congress, Chania, Sept. 2013

GROUNDWATER QUALITY OF THE COASTAL AQUIFERS IN THE EASTERN PART OF THERMAIKOS GULF (FROM AGGELOCHORI TO KALLIKRATEIA)

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Abstract

The study area is located in the coastal area of the eastern Thermaikos Gulf, covering an area of 252 km^2. The area is characterised by intense agricultural activity, and during the past few years it has undergone considerable residential development. From a geological point of view, the area consists of Quaternary alluvial coastal deposits, river terraces and Neogene deposits (marly limestones and sandstone-marl series). The bedrock formations are Jurassic limestone and Mesozoic granite. The main aquifer system is developed within the sand, gravel, and sandstone layers of the Quaternary deposits as well as within the sandstone-marl series. This paper investigates the relationship between the groundwater quality and groundwater level. Groundwater sampling and water level measurements took place in April and September 2010. The results of chemical analyses indicate degradation of the groundwater quality. The sources of the groundwater pollution are seawater intrusion due to the overexploitation of the coastal aquifers, fertilizers from the agricultural activities and the disposal of untreated wastewater in torrents.
***Key words**: over-pumping, water level drawdown, salinization.*

Περίληψη

Η περιοχή έρευνας καταλαμβάνει το παράκτιο τμήμα του ανατολικού Θερμαϊκού κόλπου, καλύπτοντας έκταση 252 Km^2. Η περιοχή χαρακτηρίζεται από έντονη γεωργική δραστηριότητα, ενώ τα τελευταία χρόνια παρουσιάζει μεγάλη οικιστική ανάπτυξη. Γεωλογικά η περιοχή αποτελείται από Τεταρτογενείς αποθέσεις και Τριτογενείς αποθέσεις (μαργαϊκοί ασβεστόλιθοι, ψαμμιτομαργαϊκή σειρά). Το υπόβαθρο συνίσταται κυρίως από ασβεστόλιθους του Ιουρασικού και γρανίτη του Μεσοζωικού. Η κύρια υδροφορία της περιοχής αναπτύσσεται σε στρώματα άμμων, χαλικιών, καθώς και ψαμμιτών των Τεταρτογενών αποθέσεων και της «ψαμμιτομαργαϊκής σειράς» που εναλλάσσονται με αργίλους. Στην εργασία αυτή γίνεται σύγκριση της μεταβολής της ποιότητας του υπόγειου νερού σε συνάρτηση με τη μεταβολή της στάθμης του υπόγειου υδροφόρου ορίζοντα. Πραγματοποιήθηκαν δειγματοληψίες και μετρήσεις της στάθμης του υπόγειου νερού σε 2 περιόδους (Απρίλιος 2010 – Σεπτέμβριος 2010). Λόγω της αυξημένης άντλησης του νερού για

την άρδευση και ύδρευση παρατηρείται σε ορισμένα τμήματα της περιοχής έρευνας υποβάθμιση της ποιότητας του νερού (υψηλές τιμές νιτρικών ιόντων, λόγω νιτρορύπανσης γεωργικής προέλευσης και χλωριόντων, λόγω διείσδυσης της θάλασσας), λόγω της υπερεκμετάλλευσης του υπόγειου υδροφορεά.

Λέξεις κλειδιά: *υπεράντληση, πτώση στάθμης, υφαλμύριση.*

1. Introduction

The studied area is located in the south part of Thessaloniki Prefecture, in the coastal part of Eastern Thermaikos Gulf, extending from Aggelochori–Thessaloniki (Megalo Emvolo) to Nea Kallikrateia–Chalkidiki (Figure 1). Administratively, the area belongs to the regional units (former Prefectures) of Thessaloniki and Chalkidiki and to the Municipalities of Thermaikos, Thermi, and Nea Propontida–Chalkidiki. The population is 27,447 inhabitants (National Statistical Service of Greece, 2001).

Figure 1-Topographic map of the study area.

Rapid population growth occurred since 1981, with a great intra-annual variation due to the increase observed during the summer months. The main activity of the residents in the study area is intensive agriculture. Cereals, fruit and vegetables, cotton, vineyards and olives are the main products. A few residents work in small and large industries, mostly in the Industrial Area of Lakomma, and some are self-employed (e.g. fishermen). The needs for irrigation and domestic water supply are covered by 750 boreholes. The pollution is detected in loose sediments (sandy clays, clays) of moderate to very low permeability. The main pollution sources are untreated waste effluent from oil mills and cheese dairies and uncontrolled waste disposal sites (UWDS). Pollution from the oil mill waste effluent can be associated with the high acidity of the groundwater due to the low pH (3.0–4.5), high temperature, high percentage of suspended solids and high organic load (Voudouris et al., 2000). The increased values of nitrate and chloride ions, which are mainly attributed to the agricultural activities, are associated with the use of nitrogenous fertilisers and groundwater over-pumping that favours seawater intrusion, respectively (Voudouris et al., 2004; Soulios, 2004).

1.1. Description of the Study Area

The surface of the studied area is 252.5 km^2. The perimeter is 95.6 km, the maximum length is 31.4 km and the maximum width is 16 km. The terrain is described as flat to semi-hilly, due to the significant extension of the Neogene formations of horizontal to slightly inclined layers with different hardness as well as to erosion by torrents. The elevation is generally low, except in the northeastern part of the area where the altitude of some bed formations can reach 535 m asl. The mean altitude of the area was calculated as 96.5 m using GIS, and the mean inclination was estimated to 5.1 %. The coastal areas present a very typical morphology, being alternately steep and flat. The flat coasts are formed at the stream mouths into the sea and they consist of alluvial deposits. The hydrographic network is moderately developed and has a dendritic to parallel form (Figure 1). Flow is observed during heavy rainfall, with a NNE-SSW direction, and is characterised as torrential. The bifurcation ratio has been calculated as 3.72, which indicates a naturally developing hydrographic network and drainage density equal to 1.55 km/km^2. The value of drainage frequency is estimated at 3.01/km^2.

1.2. Geological Setting

The studied area geotectonically belongs to the Interior Greek zones and specifically to Paeonia zone (Mountrakis, 2010). It consists of a Mesozoic bedrock covered by Neogene and Quaternary sediments (Lalechos & Bison, 1969; Mollat et al., 1978).

Bedrock formations:

- Early-Late Jurassic granite-granodiorite of Monopigado: biotite and two-mica granite traversed by pegmatite veins
- Jurassic limestone: fine-to medium-grained, overlaying locally thin layers of sandstone

Neogene sediments:

- Basic conglomerate series of Lower–Middle Miocene age: consists of bedrock gravels of various sizes and sandy, sandy mud to loamy cementing material
- Red clay series of Upper Miocene age: composed of red to tile-coloured silty clay with lenses of shingle-sand-sandstone with cross bedding, mud clay sand, fine marl and clay appearing at sites
- Sandstone marl series of Pontian age (Upper Miocene): consists of alternating sand layers (fine-grained to coarse-grained), clayey marl and clay, with interbedded, (not very cohesive) sandstones, breccias, fine layers of sandstone-breccias, calcareous sandstone and limestone
- Fresh-water limestone of the Pliocene period: the deposition took place in a shallow lake microenvironment (Syrides, 1990). It is a mainly marly limestone, often containing gravels and other materials of local origin.

Quaternary sediments:

- Upper terrace system of Pliocene age: mainly made up of quartzite pebbles and metamorphic rocks containing a small proportion of limestone
- Lower terrace system of the Holocene period: found in streams and mostly consists of pebbles, sand, limestone and schist pebbles
- Eluvial mantle: covers the Neogene deposits and consists of their weathering products
- Sediments of coastal lakes and lagoons: mainly sands and sandy clays
- Coastal deposits: consist of beach ridges and sand dunes
- Alluvial deposits: consist of sedimentary material (clays, sands, grits) from the weathering of Neogene formations

The area has been affected by the extensional phase of Quaternary, resulting in NNW-SSE and NE-SW main fault systems. These small and medium-scale faults have small surface traces.

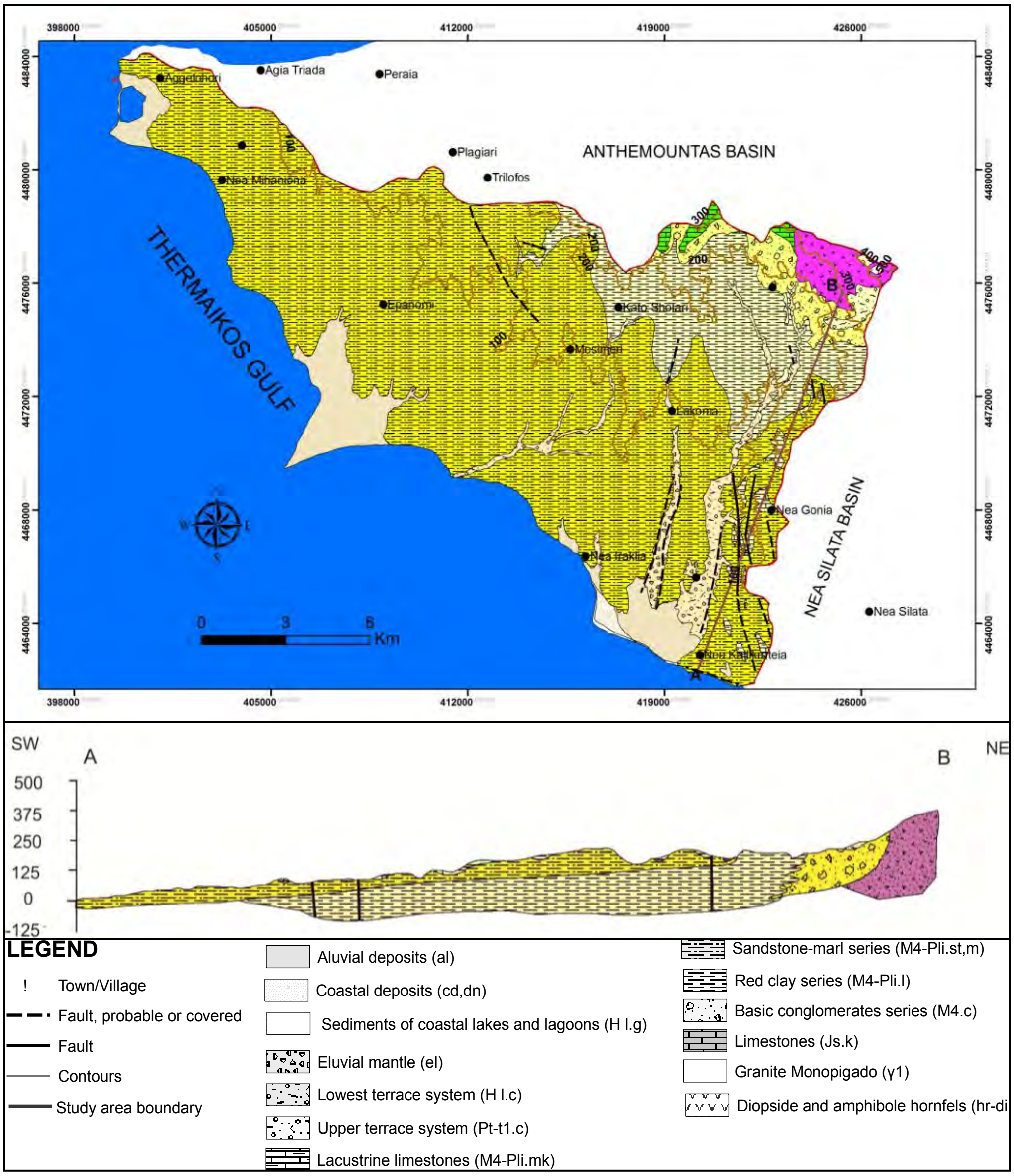

Figure 2 - Geological map of the study area and sketched geological section along settlements N. Kallikrateia-N. Gonia-Monopigado of SW-NE direction.

2. Hydrogeological Setting of the Study Area

2.1. Water Level Measurements and Results

The main aquifers have developed within the Quaternary geological formations and the fine layers of sands, sandstones and pebbles of the sandstone marl series, which covers the largest part of the area. Data from available lithological sections show that the yield of the boreholes ranges from 8 to 140 m^3/h with a mean value of 60 m^3/h. The drilling depth ranges from 40 m in the coastal part to 360 m in the central and northern part of the area, with the average depth at 210 m. The lowest yields (5–20 m^3/h) are recorded in the northern part of the area, which consists of Neogene sediments (red clays, conglomerates) and defines the recharge area of the aquifer, while the highest yields (50–140 m^3/h) are recorded in the coastal areas of Aggelohori, Mihaniona, Epanomi, and Kallikrateia. The region between the settlements of Mesimeri, Kato Sholari, Lakoma, Nea Gonia and the northern boundary of the studied area presents the most adverse hydrogeological conditions.

The upper aquifers are unconfined ($T=1–5.10^{-3}$ m^2/s; $k=1.10^{-3}$ m/s) and are formed along the torrents. The deep underlying aquifers are in confined to semi-confined conditions. According to Koumantakis (2006), the piezometric level of both aquifer systems is identical, while their hydraulic features are heterogeneous. The confined aquifers are mostly characterised by good to moderate groundwater capacity ($T=1.10^{-3}–1.10^{-5}$ m^2/s; $k=5.3.10^{-5}$ m/s). The transmissivity in some parts of the hilly area (Trilofos – Kardia – Kallikratia – Nea Gonia) is relatively low ($T \leq 10^{-5}$ m^2/s), resulting in low borehole yields (15–20 m^3/h) from the depth of 350 m (Institute of Geology & Mineral Exploration/IGME, 2008; Papageorgakakis & Koumantakis, 1978).

The groundwater level in the area was measured in 80 boreholes used for various purposes (irrigation, water supply, etc). According to the international specifications, each measurement was preceded by pumping interruption for an adequate time period, there was no pumping during the measurements in the neighbouring area and the same measurement was always performed from the same point using the same instrument. Measurements of the water level were carried out during both the wet and dry periods, in April 2010 and September 2010, respectively.

It was shown that the maximum depth of the groundwater level in April 2010 was 148.7 m (below ground surface) and the minimum was 0.44 m (b.g.s.), while in September 2010 the corresponding depths ranged from 0.45 m to 149.32 m. A water table map is shown in Figure 3 (the groundwater level values are measured above the sea level). The groundwater flow lines follow the NE-SW direction and groundwater flows from the internal part of the basin to the coastal part. The negative values of the water level contours, occurring mostly near the coastal zone, indicate that the intrusion of seawater is possible. The groundwater level drawdown (Figure 4) observed between the two periods ranges from 5.84 m to 0.01 m, while the average value is about 1 m. The highest drawdown is observed in the southern part of the area, where the largest increase in resident population and visitors is recorded during the summer months, resulting in increased water needs.

2.2. Groundwater Sampling and Results

Groundwater sampling was carried out at the end of the wet and dry periods (April and September) of 2010. These periods represent the highest and lowest groundwater levels and are considered to be the most suitable for studying any changes in hydrochemical parameters. Fifty nine (59) samples were collected at the end of the wet period and sixty three (63) samples at the end of the dry period. In situ measurements of pH and electrical conductivity (E.C.) were conducted, while the value of major ions concentration (Ca^{2+}, Mg^{2+}, Na^+, K^+, HCO_3^-, Cl^- , SO_4^{2-} and NO_3^-) was determined in the Engineering Geology & Hydrogeology Laboratory, Dept. of Geology, Aristotle University.

Based on the results of chemical analyses, it is concluded that the cation composition of the groundwater is Ca>Mg>Na>K, except for samples from the coastal zone, where Na is the predominant cation. The anion composition of the groundwater is HCO_3>Cl>NO_3 (fresh water) or Cl>HCO_3>NO_3 (water affected by seawater intrusion). The Ca-Mg-HCO_3 chemical water type is the dominant type in inland areas (fresh water) and Na-Cl water type is the type of water affected by seawater intrusion in coastal areas.

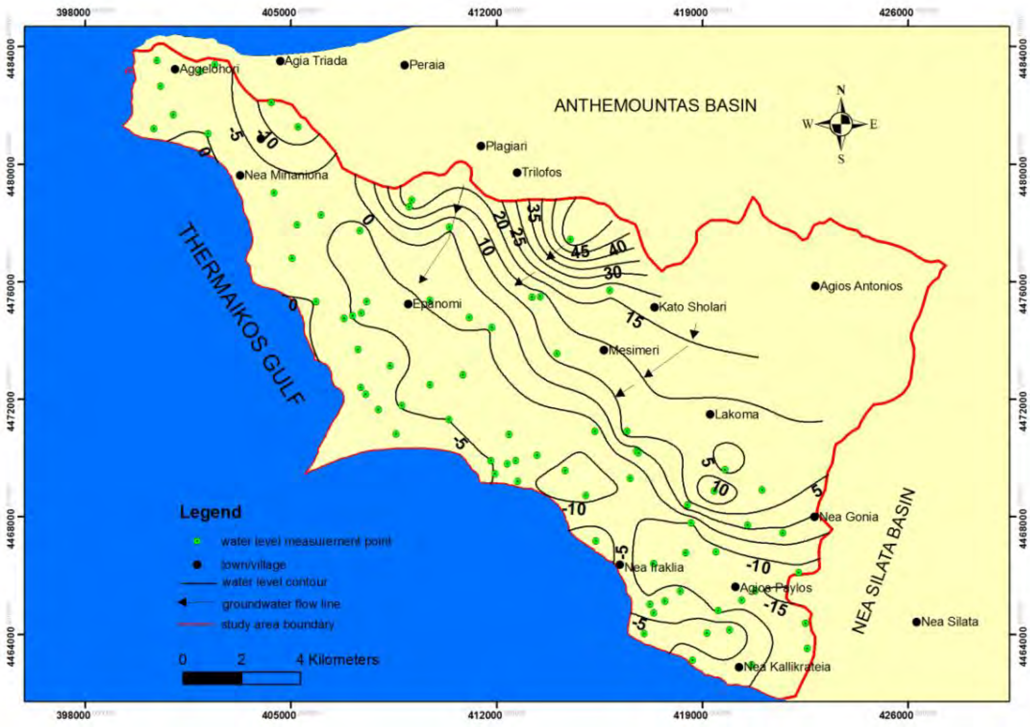

Figure 3 -Water table map, April 2010.

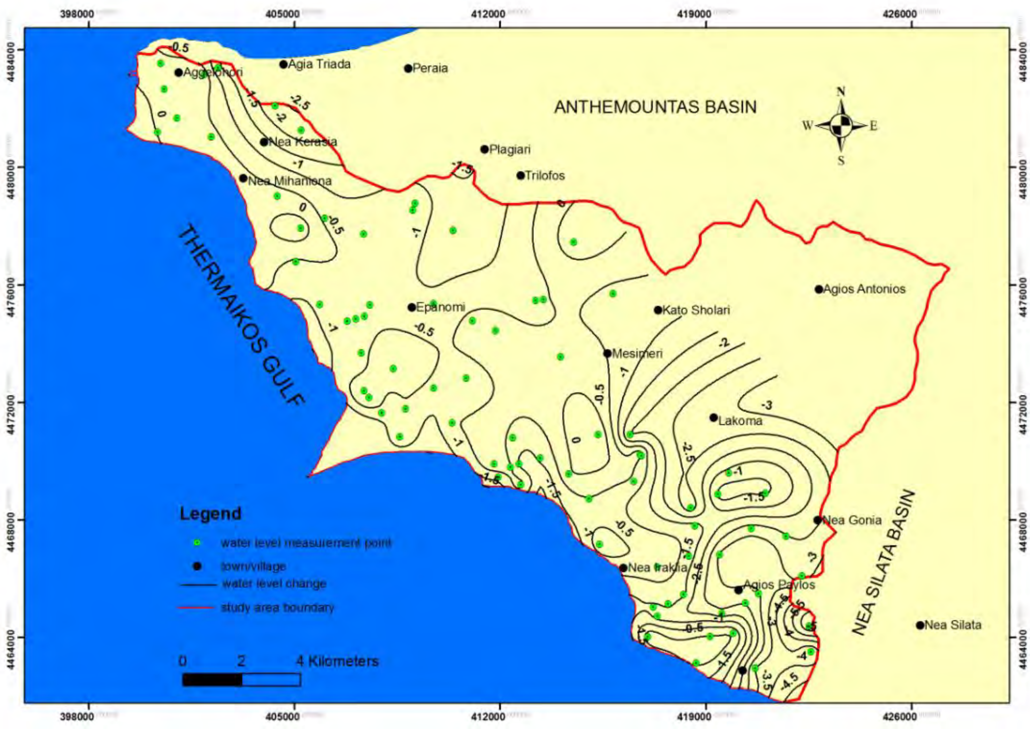

Figure 4 -Water level change during the period of April 2010-September 2010.

High concentrations of Cl^-, Na^+ and NO_3^- ions are locally recorded, rendering most of the samples not suitable for drinking. Regarding the nitrates, the NO_3 concentration exceeds the maximum admissible limit of 50 mg/l (set by EU Council for drinking water) in 30 % of the boreholes, rendering groundwater unsuitable for human consumption. Increased concentrations in chloride ions and nitrates are recorded in the coastal zone and are clearly attributable to the seawater intrusion due to groundwater over-pumping to meet irrigation demands.

The problem of salinisation of the coastal aquifers has been examined by many researchers in Greece (Diamantis & Petalas, 1989; Petalas & Diamantis, 1999) and worldwide (Henry, 1970; Todd, 1953; Pulido-Leboeuf, 2004), as it is among the main causes of groundwater degradation in coastal areas. Figures 5 and 8 illustrate the spatial distribution of chloride and nitrate ion concentration, respectively, in the study area. The change in chloride ion concentration between dry and wet periods is depicted in Figure 6. It emerges that during the dry period the value of chloride ion concentration is higher than during the wet period in the majority of groundwater samples. This increase in the coastal areas is obviously attributed to the seawater intrusion due to water level drawdown. The groundwater level change in relation to the chloride ion concentration change between the two periods is illustrated in Figure 7. As can be seen from the diagram, the chloride ions tend to rise as the groundwater level decreases. On average, an increase in chloride ions by 25 mg/l is observed with a 1 m groundwater level drawdown. In addition, there is a decline in nitrates from the wet to the dry period. This can be explained by the fact that fertilisation takes place during the summer months, while infiltration and transportation from the upper soil layers to the aquifers is much higher during winter due to rainfall. The effect of fertilisation on the groundwater quality is evident after the infiltration processes are completed.

Figure 5 - Spatial distribution of chloride ions concentration (April 2010).

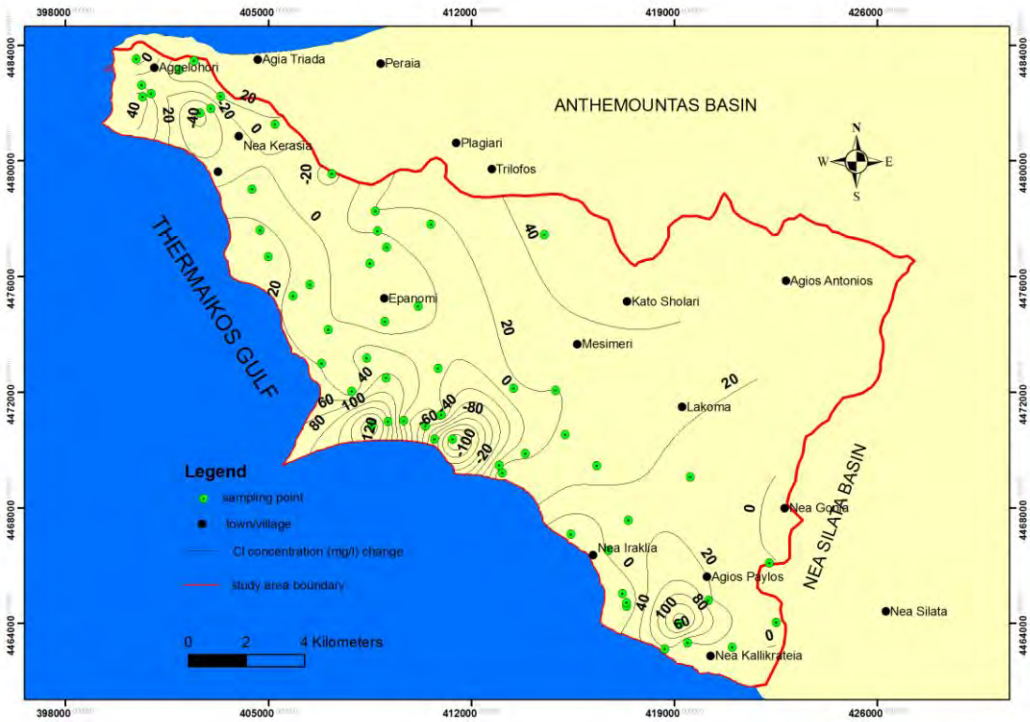

Figure 6 - Chloride ions concentration change, during the period April 2010- September2010.

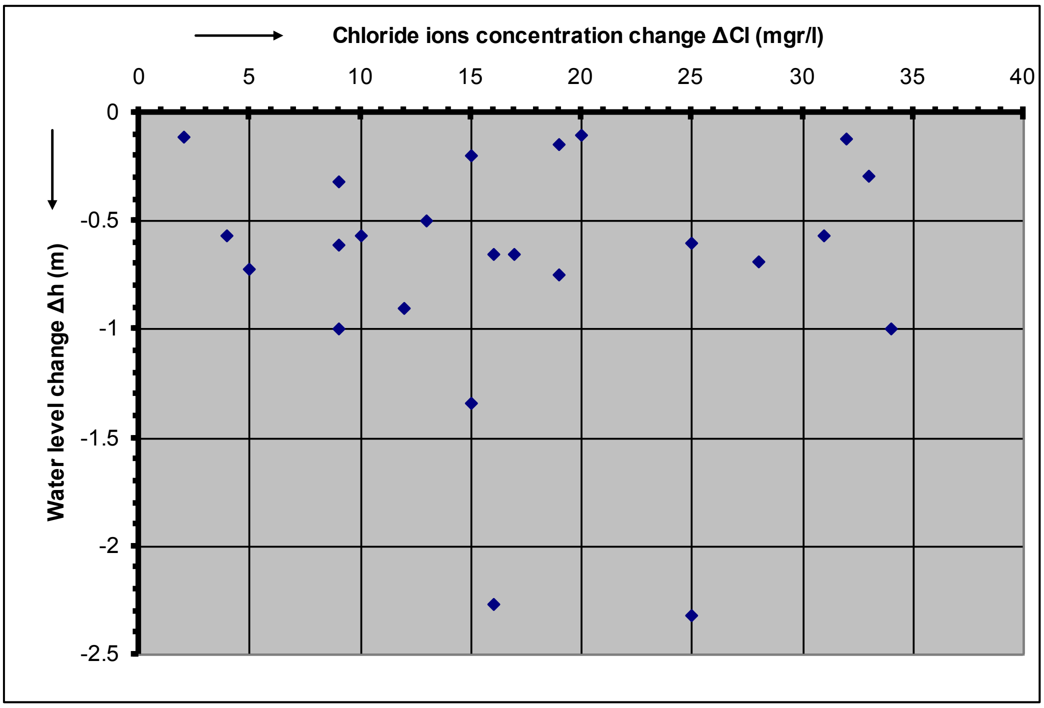

Figure 7 - Relation between water level change and Cl$^-$ concentration change during April 2010- September 2010.

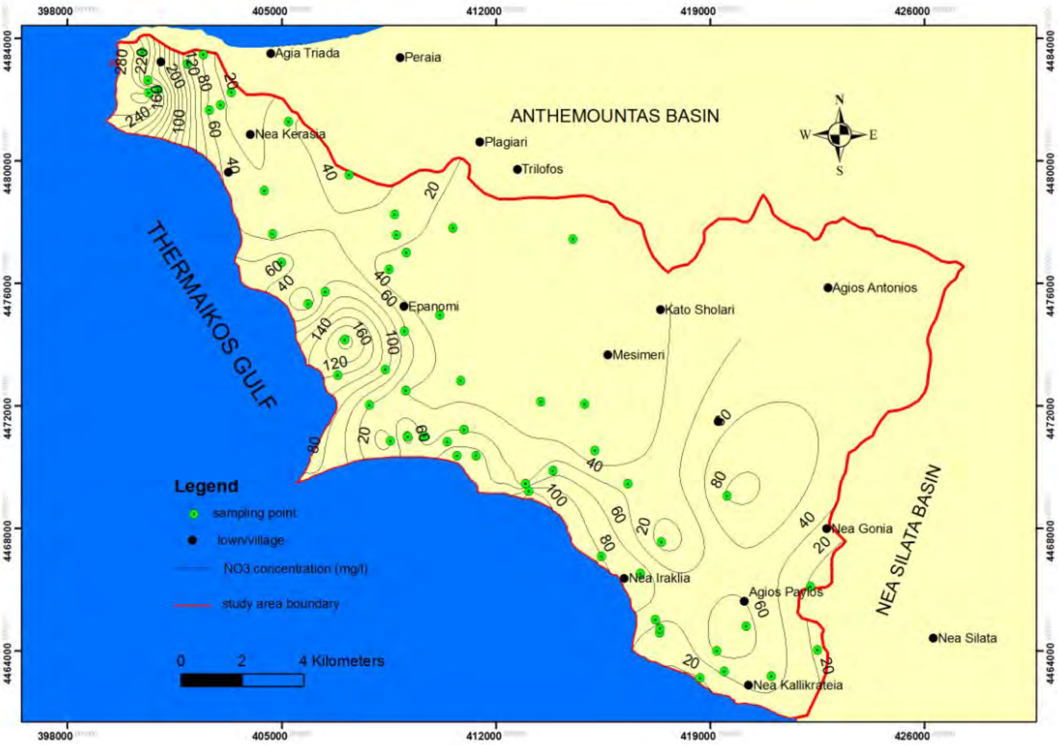

Figure 8 - Spatial distribution of nitrate ions concentration (April 2010).

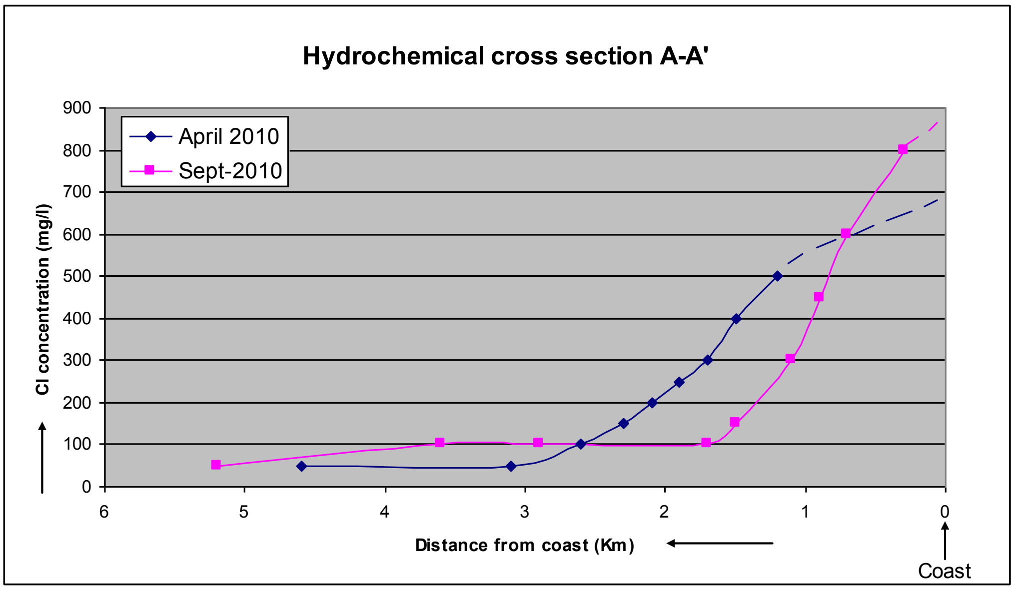

Figure 9 – Hydrochemical cross section (Cl^- concentration).

At a distance of 2.5 km from the coast an increase of the Cl^- concentration was observed according to the hydrochemical cross sections in Figure 9. Seawater intrusion is insignificant in inland areas. An intra-annual fluctuation is also observed, with high Cl values at the end of the dry period (September).

3. Conclusions

An increased concentration of chloride ions has been detected in the coastal zone of the studied area, attributed to seawater intrusion as a result of over-pumping and groundwater level change. There is also an increased concentration of nitrates due to the use of nitrogenous fertilisers for agricultural purposes. The nitrate concentration decreases during the dry period owing to over-pumping and increases at the end of the wet period due to infiltration. A systematic monitoring programme for both quality and quantity should be established in selected boreholes to mitigate seawater intrusion phenomena and nitrate pollution on a large scale.

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