Spatio-temporal analysis of groundwater pollution from BTEX in Thriassio Field, Attica, Greece

PANAYOTA MAKRI[1], MICHAEL SCOULLOS[2], DIONISSIOS KALIVAS[3], GEORGE BATHRELLOS[4] & HARIKLIA SKILODIMOU[5]

[1] *National and Kapodistrian University of Athens, Zografou, 157 84, Gr. (e-mail: pmakri@geol.uoa.gr)*
[2] *University of Athens, Zografou, 157 77, Gr (e-mail: scoullos@chem.uoa.gr)*
[3] *Agricultural University of Athens, Athens118 55 Gr. (e-mail: kalivas@aua.gr)*
[4] *National and Kapodistrian University of Athens, Zografou, 157 84. Gr.(e-mail: gbathrellos@geol.uoa.gr)*
[5] *National and Kapodistrian University of Athens, Zografou, 157 84. Gr.(e-mail: hskilodimou@euof.uoa.gr)*

Abstract: The Thriassio Field is the biggest industrial area in Greece and is located in western Attica, 25 kilometres northwest of Athens. Its basin comprises three urban areas: Elefsina, Aspropyrgos and Mandra. Today, this region, which used to be a productive ecosystem, has become the most polluted area of Greece because of the uncontrolled industrialization which has occurred in the last 50 years. Among the several types of polluting industries in the region, this paper focuses on the petroleum industry. Since the potential for groundwater pollution is strongly affected by the particularities of the aquifer in this region. This paper investigates whether there is migration of the main volatile components of petroleum within the hydrological system of the Thriassio Field.

A number of groundwater samples were collected twice a year for a two year period. The target pollutants including benzene, toluene, ethyl benzene and total xylenes (BTEX) were identified with Gas Chromatography/ Mass Spectrometry (GC/MS). These pollutants are priority water pollutants according to the Environmental Protection Agency (EPA). Non-spatial and spatio-temporal statistical analysis of the laboratory measurements was performed in a GIS environment (ArcMap, Geostatistical Analyst), which enabled spatial correlation of the analytical data with land resources data (e.g. lithological formation) of the study area.

Résumé: La Plaine de Thriassio est une région industrielle qui se trouve à l'ouest d'Attique; Elle y comprend trois régions rurales: Elefsina, Aspropyrgos, et Mandra. Bien que la région d'étude ait été un habitat productif à l'antiquité, l'industrialisation incontrôlée dans les années contemporaines l'a mise en péril. Ce document s'en rapporte aux industries de pétrole qui contribuent apparemment à la pollution des eaux souterraines, par l'effusion du pétrole aux nappes phréatiques. Les hydrocarbures investigués sont le benzène, le toluène, l'éthyle benzène, et les xylènes connus comme BTEX. Les résultats de la caractérisation chimique ont été élaborés par un Système d' Information Géographique (SIG) qui a abouti à une analyse statistique appliquée aux données spatio-temporelle.

Keywords: Petroleum products, groundwater contamination, aquifer, wells, geographic information systems

INTRODUCTION

The contamination of soils and groundwater by petroleum hydrocarbons has been of major concern over the last two decades. The most frequent cause of contamination is leakage from underground pipelines, spillages from overfilling or accidents during transferring fuel (Moore, 1992). When pollution occurs, a number of dangerous substances may migrate through groundwater, enter into the food and water chain, and finally directly or indirectly harm man. The investigation of sites contaminated by petroleum hydrocarbons is complicated because of the existence of complex geological and hydrogeological settings (Hiscock, 1995).

Fuels composed of hydrocarbons such as gasoline, heating fuels, kerosene and jet fuels contain a significant percentage of benzene, toluene, ethyl benzene and xylenes, mostly known with their acronym BTEX. These compounds are monocyclic aromatic hydrocarbons, soluble in water, volatile and very mobile. They are found principally, in petroleum products and also in other industrial products such as plastics, pesticides, explosives and paints (Fitt, 2002).

When the BTEX compounds enter the water or food chain this can be fatal for human life, causing harm in the short or long term. Specifically, benzene, which is both carcinogenic and mutagenic is considered one of the priority pollutants according to the Environmental Protection Agency (EPA) National Primary Drinking Standards.

Once pollution of groundwater has occurred, the remaining hydrocarbons provide a continuing source of pollution in the underground strata. Where the density of the contaminant plume is significantly greater than that of groundwater, the contaminant plume may migrate downwards to the aquifer, so that it cannot be detected by shallow monitoring systems (Kallergis, 2000).

The present study is an attempt to investigate whether BTEX pollution has migrated to the aquifer at depth producing a potential plume of pollution in the Thriassio Field, Western Attica, Greece. Results from the laboratory analysis of groundwater sampling have been assessed using spatio-temporal processing in a GIS environment.

DATA, HYDROGEOLOGY AND METHODOLOGY

Study area

Thriassio Field is one of the three basins of the Attica Prefecture, 25 km west of Athens (Figure 1). It covers a total surface area of 345 km^2, and has a smooth relief with low altitudes from 0 to 100 m above sea level. The drainage network is poorly developed and comprises streams with seasonal flow that drains to the Saronikos Gulf, south of the Thriassio Field.

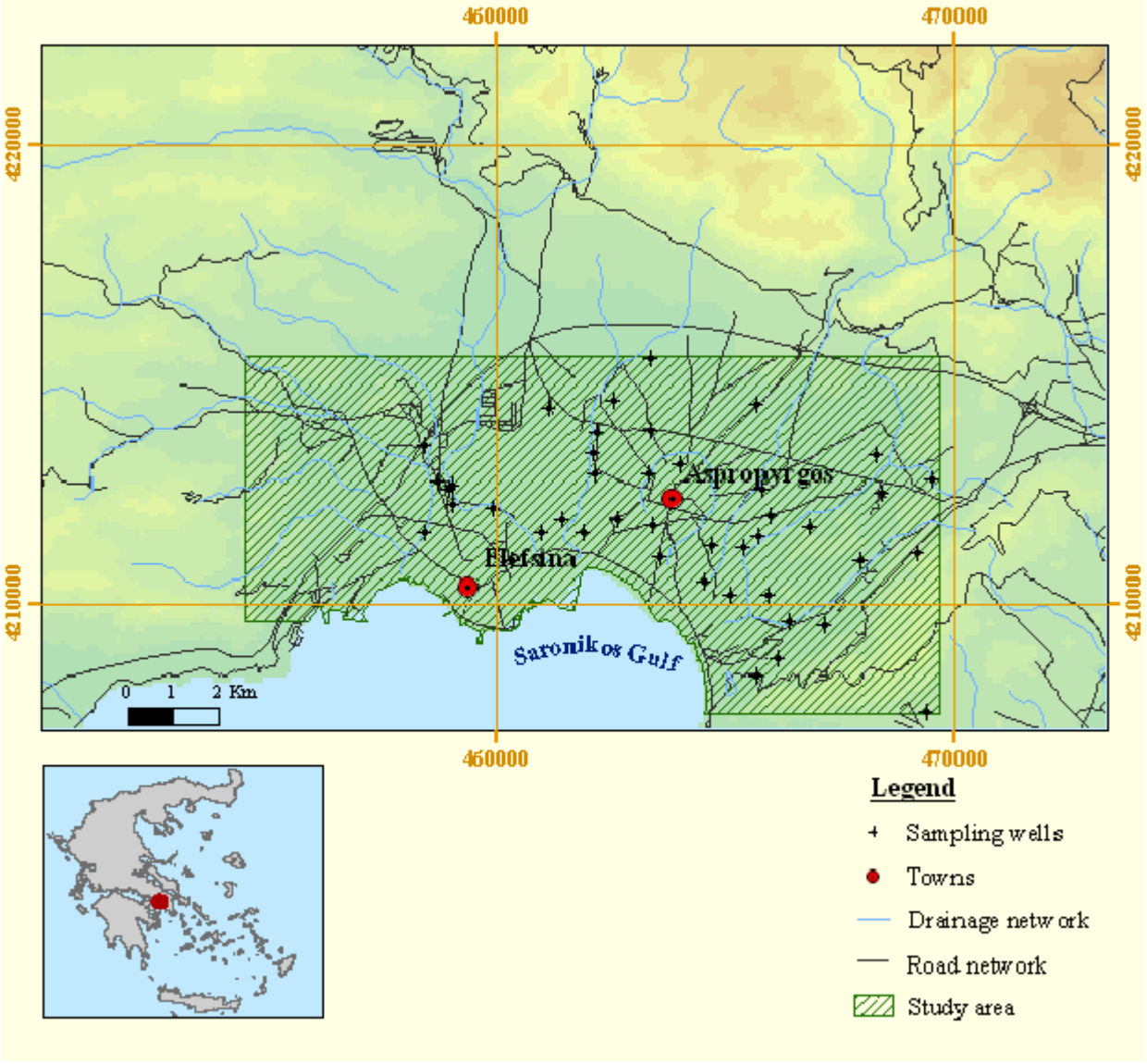

Figure 1. Study area and locations of sampling wells.

The Thriassio Field was a famous agricultural and cultural centre of Greece for almost 2000 years. Today, the uncontrolled land planning and industrialization has turned the area into one of the most polluted locations in the Mediterranean. The basin comprises three urban areas: Aspropyrgos, Elefsina and Mandra, and has been strongly industrialized over the last four decades. The industries established and operating include Hellenic Refineries (in two different locations, one in Aspropyrgos – known as ELPE and the other which lies west of Elefsina – known as Petrola), a petroleum recycling unit: CYCLON, steel manufacturing and processing at Halivourgiki, and approximately 40 other industries of less environmental burden. Additionally, the Military Airfield of Elefsina is located in the study area, at the western side of Elefsina.

The environmental problem of the Thriassio Field has been studied for many years by various organizations (governmental and non-governmental) that have identified heavy metals in the soil and groundwater (Kaminari, 1994). Specifically, for the Refinery of Aspropyrgos (ELPE), Kounis and Siemos (1987), and McCartney *et al.,* (1997) have reported leakages of petroleum hydrocarbons in the subsurface of the Hellenic Refinery. Hence, the Hellenic Refinery has undertaken remediation to address this contamination. It should also be noted that the Saronikos Gulf, the receptor of the drainage system of the Thriassio Field, is environmentally burdened by marine and shipyard activities (Skoullos and Riley, 1978).

GEOLOGICAL AND HYDROGELOGICAL SETTINGS

The geological formations of the study area are developed as follows: Arkose, Greywacke and clay shale of the Upper Carboniferous - Permian, Phyllite and sandstone of the Lower-Medium Triassic, Limestone and dolomites of the Medium-Upper Triassic to the Upper-Lower Jurassic and transgression limestone of the Upper Cretaceous, Conglomerates over some alternations of bauxite, Neogenic deposits (marls, clays, and sandstone along with Pleistocene continental deposits) and alluvial deposits, debris cones and lateral deposits of the Holocene (Katsikatsos, 1992).

There are two major aquifers in the broader area of the Thriassio Field, from the Hellenic Refineries up to the basin of Megara. Firstly a karstic formation of Mesozoic limestone and dolomite, located at the circumference of the Thriassio basin and the northeastern side of the Hellenic Refinery and secondly a Neocene granular formation made of transferred material, either loose or connected, with multiple sorting and mechanical properties (Kounis and Siemos, 1991). The major surface of ELPE has been constructed on the latter. The sampling area extends onto the Holocene alluvial deposits. The loose material and the conglomerates within the alluvial deposits, along with the topsoil may be considered semi-permeable since it contains parts of compact blocks and parts of loose material. The karstic formation is considered permeable and is an aquifer that provides a good water supply (Parashoudis, 2002).

In the present study, the groundwater samples were acquired from the conglomerate aquifer, which behaves as a permeable unit if it is loose, and as non-permeable unit if it is connected. The depth to groundwater was measured from 1 to 6 metres above sea level, forming local mounds or depressions in the groundwater surface. Groundwater contouring has shown a general flow direction towards the coastline. It is also important to note that there is an inflow of seawater to land, causing deterioration of the groundwater quality (Kaminari, 1994). The flow of seawater to land is principally a result of the uncontrolled pumping of groundwater at existing wells or boreholes to serve the needs of the urban and industrialized areas within the Thriassio basin.

Data used

This study was accomplished using the following data:

- Topographic maps of the study area, scale 1: 50.000, of Hellenic Geographical Military Service;
- Geological maps, sheet Elefsis, scale 1:50.000, issued by the Institute of Geological and Mineral Exploration (IGME), 1980; and
- Field work and sampling (site investigation).

METHODOLOGY

Sampling

Sampling was undertaken twice per year: once in October 2003 and again in May 2004; these two months represent the lowest and highest water levels within the aquifer respectively. The samples were collected according to the EPA's method 524.2, which concerns both the sampling, storing and chemical analysis of the target analytes (i.e. BTEX). The total area covered by the sampling programme was 72 km^2. An in-situ investigation of the registered wells resulted in the selection of the 43 monitoring points reported in this paper. Selection was based upon those wells neighbouring pollutant sources and allowing suitable access. Glass bottles of 40 ml volume were used to collect the samples, ensuring minimum headspace to avoid volatilization of the target analytes, and all samples were sealed with septa. The samples were stored below 4 ^{o}C before laboratory analysis which was undertaken within 15 days to avoid decomposition of the target compounds.

Sampling preparation and laboratory analysis

The method applied to concentrate the target analytes (BTEX) from the water volume was Solid Phase Microextraction (SPME). With SPME, the concentration of the target analytes occurs by the immersion of a specific fused silica fibre directly into the sample bottle, without any contact with dangerous solvents (Vas and Vekey, 2004). After initial testing of samples, the fibre selected was a 100 μm PolyDiMethylSiloxane (PDMS). The concentration lasted for 30 minutes with no heating.

As soon as the samples were concentrated, they were analyzed with Gas Chromatography and then detected with a Mass Spectrometer (GC/MS) according to the analytical method EPA 524.2.

The analysis method to trap and separate the BTEX in the Varian- Star 3400CX, was as follows:

- *Column Temperature:* 5 ^{o}C for 3 min to 25 ^{o}C, rate: 25 ^{o}C/ min to 142 ^{o}C, rate 6 ^{o}C/min;
- *Injector:* 250 ^{o}C (or 15^{0}C to 250 ^{o}C, rate 250 ^{o}C/min);
- The detection occurred in a Mass Spectrometer Varian Saturn 2000; and
- The detection limits of the target analytes are a) benzene: 30 ppt, b) toluene 20 ppt, c) ethyl benzene: 10 ppt, d) total xylenes: 20 ppt.

The results of the chemical identification were quantified and thus the final concentrations were obtained.

Data process with Geographic Information System

A geographical database was developed using ArcGIS ver. 9.0 (ESRI, 2004) software. The following data layers were digitized and stored in the database:

- Sampling well locations with the analytical data;
- Main industries; and
- Drainage network, road network, towns, topographic contours of the area.

Using the Geostatistical analyst extension of ArcGIS, the initial values of each parameter (i.e. concentration BTEX compound) for the two sampling seasons were interpolated in grid layers with a cell size of 20 x 20 metres. The Inverse Distance Weighted (IDW) method was used to interpolate the data obtained. The following contour maps provided refer to the concentrations of each target analyte for the two seasons (autumn, October 2003; and spring, May 2004).

RESULTS

Table 1 presents the results from the GC/MS analysis of BTEX, for the two sampling seasons.

Non spatial analysis

The laboratory results are demonstrated in Table 1. Contaminant concentrations are expressed in ng/l (parts per trillion-ppt) of benzene (Benz), toluene (Tol), ethyl-benzene (Eth-be) and o, m, p, xylenes (Tot_Xyle) obtained from the laboratory analysis and quantification. The number of sampling wells (N) is 43, and the "well id" is the identification number used by the authors to recognize the wells. In addition, descriptive statistics of the data, including the minimum, maximum, mean and standard deviation values are also given. Where the concentration of the contaminant was found to be below the detection limit, this is declared as "nd" non detectable.

Table 1. Values of BTEX in ppt (ng/l)-during two seasons (Autumn 2003, and Spring 2004) and their descriptive statistics, where "nd" stands for non detectable.

N	Well id	Autumn				Spring			
		Benz	Tol	Eth-be	Tot Xyle	Benz	Tol	Eth-be	Tot Xyle
1	8	10275	1500	31941	36567	1000	nd	18	97
2	1000	781	550	100	650	nd	nd	11	40
3	16	530	200	450	680	nd	nd	22	157
4	23	40	nd	316	440	nd	nd	nd	87
5	29	750	630	250	435	nd	nd	14	99
6	38	nd	nd	100	250	nd	nd	12	154
7	44	2163	1320	33	42	100	nd	15	160
8	45	245	nd	100	1500	nd	nd	24	112
9	54	17570	3125	3194	5736	60	nd	nd	56
10	61	117	nd	94	96	nd	nd	15	108
11	62	nd	nd	70	90	150	nd	24	211
12	63	1600	250	136	210	nd	nd	16	133
13	72	202	nd	419	551	210	nd	33	216
14	88	102	nd	212	146	nd	nd	nd	nd
15	95	544	nd	120	540	nd	nd	nd	nd
16	98	1546	1100	268	382	nd	nd	nd	nd
17	100	40	nd	317	356	nd	nd	25	45
18	102	822	nd	nd	121	80	nd	18	57
19	106	900	300	25	100	42	nd	nd	nd
20	136	911	250	182	308	35	nd	47	102
21	142	nd	nd	20	21	nd	nd	nd	nd
22	152	nd	nd	nd	nd	nd	nd	nd	nd
23	169	nd	nd	nd	nd	nd	nd	nd	69
24	187	nd	nd	nd	nd	33	nd	23	126
25	1	700	nd	407	400	nd	nd	nd	nd
26	3	2500	450	22145	24033	nd	nd	38	203
27	12	30000	1000	1150	26000	13679	nd	340	10758
28	2000	985	nd	815	875	120	nd	100	95
29	3000	5200	490	80	125	nd	nd	nd	40
30	47	468	nd	28	28	nd	nd	14	28
31	55	2700	560	90	112	nd	nd	nd	nd
32	67	295	nd	nd	nd	nd	nd	nd	92
33	4000	56	nd	239	261	nd	nd	11	57
34	5000	1800	nd	37	59	nd	nd	nd	nd
35	202	50	nd	nd	nd	nd	nd	nd	nd
36	6000	nd	nd	25	176	nd	nd	nd	nd
37	7000	100	nd	nd	nd	500	nd	nd	nd
38	8000	238	4560	nd	nd	nd	200	nd	nd
39	9000	305	9903	nd	nd	nd	500	nd	nd
40	10000	100	3214	nd	nd	nd	100	nd	nd
41	11000	104	172	nd	nd	nd	nd	nd	nd
42	12000	200	6500	nd	nd	nd	2500	nd	nd
43	13000	nd	nd	nd	nd	nd	nd	nd	nd
Minimum		40	172	20	21	33	100	11	28
Maximum		30000	9903	31941	36567	13679	2500	340	10758
Mean		3862	750	10830.3	12632.3	1452.4	825	41	532
Std. Dev.		5860.6	2589.1	6923.5	8752.9	3749.3	1129.5	73.2	2131.0

Before any discussion of the contaminant concentrations, it is important to refer to the Maximum Contamination Limit (MCL), which is the limit value above which immediate remediation is necessary. According to the EPA, the MCL of benzene is **0.005 ppm** (mg/l) or 5 ppb or 5,000 ppt. The MCL's of the other target analytes are: **1 ppm** (1,000 ppb or 1,000,000 ppt) for toluene, **0.7 ppm** (700 ppb, or 700,000 ppt) for ethylbenzene and **10 ppm** (or 10,000 ppb or 10,000,000 ppt) for xylenes. In this research, the number of samples of benzene above the MCL is four (4), during autumn and one (1) in spring. As for toluene, ethylbenzene and xylenes, no value is over their respective MCLs either in autumn 2003 or in spring 2004.

With respect to the minimum and maximum BTEX concentrations, the following may be concluded: detectable concentrations of benzene range from 40 ppt to 30,000 ppt (or 30 ppb) during autumn 2003, and from 33 ppt to 13,679 ppt (or 13 ppb) in spring 2004. Detectable concentrations of toluene range from 200 ppt to 3125 ppt (or 3,1 ppb) in autumn 2003 and there are no detectable concentrations in spring 2004. Detectable concentrations of Ethyl benzene range from 20 ppt to 31,941 ppt (or 31 ppb) in autumn 2003 and from 11 ppt to 340 ppt in spring 2004. Finally, detectable concentrations of total xylenes range from 21 ppt to 36,567 ppt (or 36 ppb) in autumn 2003 and from 28 ppt to 216 ppt in spring 2004.

The standard deviation is high for all of the BTEX compounds in both monitoring seasons, except ethyl benzene in spring 2004. The generally high standard deviations illustrate the range in BTEX concentrations observed across the

study area and may indicate the presence of a mobile source of pollution and, thus, seasonal rates of BTEX migration within the aquifer.

Overall, the concentrations of BTEX in autumn 2003 were much more elevated than those in spring 2004. This may suggest that winter rainfall has "flushed" pollution from the wells, causing greater dissolution of the contaminants of concern.

Spatial analysis

BTEX, are not commonly found "naturally" in the environment (as for example are metals such as Lead and Zinc, which, in excessive concentrations will be considered as "pollution"), and since BTEX are hazardous for human health, it could be considered that every concentration over a non-detectable concentration may be considered as pollution or contamination. The value classification in the following maps is different among the four target analytes. If a target analyte has a wide range of concentrations (e.g. xylenes), there are more classes in the GIS map. The following comments relate to the range in concentrations of the BTEX compounds:

- For benzene: a concentration from the detection limit up to 500 ppt can be regarded as negligible, from 500 to 1000 ppt (0.5 ppb –1 ppb) as low, from 1000 ppt (or 1 ppb) up to 5000 ppt (or 5ppb) as moderate and, finally, the pollution over 5000 ppt which is over the Maximum Contaminant Limit as high. Therefore, for benzene in autumn, sixteen (16) wells are of negligible pollution, nine wells have low pollution, six (6) wells have moderate pollution, and four (4) are highly polluted. In spring, ten (10) wells are below 1 ppb and one (1) has the value of 13,6 ppb that is high;
- For toluene the concentrations can be assumed as negligibly low as the values are much lower than the MCL (1,000,000 ppt); thirty one (31) wells are below 1 ppb and twelve (12) are up to 10 ppb, in autumn 2003. Only one well has a concentration of 2.5 ppb in spring;
- For ethyl benzene in autumn 2003, forty one (41) samples are between non-detectable concentrations and 3 ppb, and only two are higher at 22 ppb and 31 ppb. For spring 2004, almost all values are close to the detection limit. The pollution is considered negligible to low, since the MCL is very high: 0.7 ppm (700 ppb); and,
- Xylenes present a wide range of concentrations, thus, for the spatial analysis more classes were calculated than for the other compounds. In general, both for autumn 2003 and spring 2004, the concentrations are low to moderate since the MCL is very high: 10 ppm (or 10,000 ppb).

Figure 2 depicts the distribution of benzene in autumn 2003. The pollution is accumulated into three "spotted" areas: a) along the eastern, southern and western boundaries of the Military Airfield of Elefsina, with the highest concentrations being 17 ppb, 5.2 ppb and 1.5 ppb; b) southeast of the town of Aspropyrgos, where various non-petroleum industries are situated with a concentration of 30 ppb; and, c) northeast of the Hellenic Refinery of Aspropyrgos with a concentration of 10 ppb.

Groundwater pollution was expected to be identified northeast of the refinery area, though some of the pollution will have been addressed as a result of the remediation program instigated at this site. The data suggests that the pollutants in this location "fade out" or decrease to the North.

The BTEX concentrations in the area along the peripheral boundaries of the military Airfield are located to the east and north east of the Airfield. This pollution potentially results from either an underground leakage of petroleum products or a surface pollution incident introduced to the aquifer by infiltration of rainfall.

With respect to the pollution outside of the Aspropyrgos area, these are the highest concentrations of all of the wells studied. The existence of a BTEX plume is obvious but its source is unlikely to be the CYCLON company because this is a newly constructed unit and the site is located "outside" of the pollution contours.

Benzene

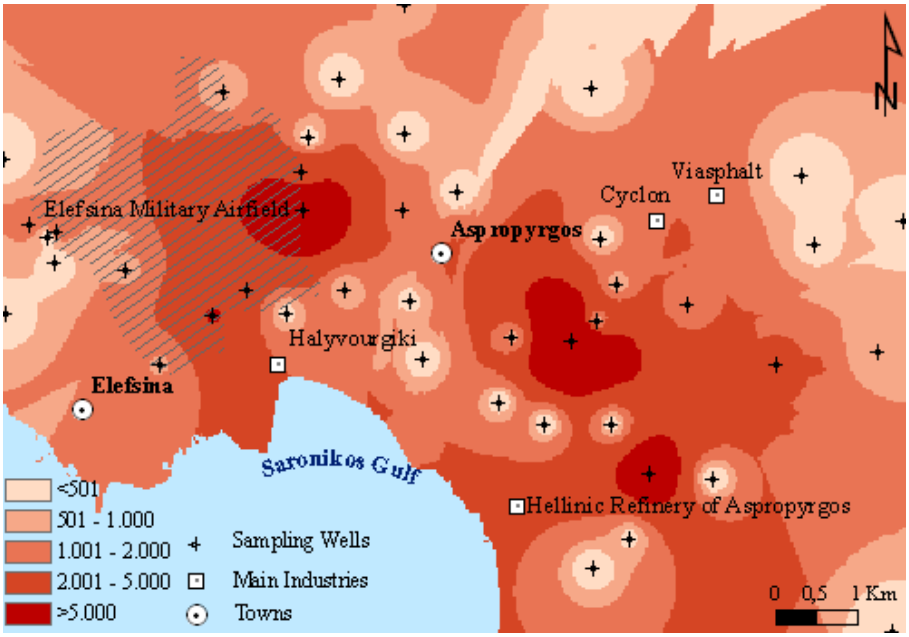

Figure 2. The spatial distribution of Benzene concentrations in groundwater (in ppt) in the Thriassio Field during autumn 2003.

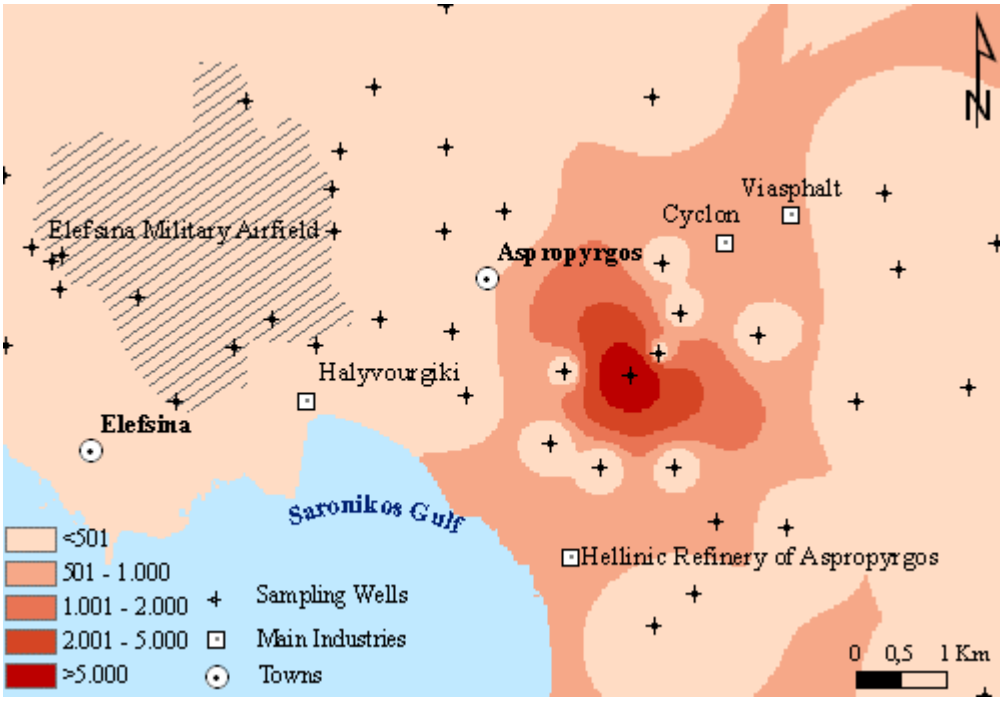

Figure 3. The spatial distribution of Benzene concentrations in groundwater (in ppt) in the Thriassio Field during spring 2004.

Figure 3 depicts the distribution of benzene in groundwater in spring 2004. These concentrations are more moderate than high but the general shape of the detectable plume is the same as in autumn 2003. The three polluted areas now reduced to one, outside of the town of Aspropyrgos. There appears to be a tendency for the pollution to "spread" or "migrate" to the north and to the east. This migration of the BTEX plume appears to contradict the general direction of groundwater flow towards the Saronikos Gulf. With respect to the pollution of the Military Airfield, this can be considered as low in spring 2004 as in the area to the northeast of the Hellenic Refinery there is only one location with a detectable concentration of benzene of 1 ppb.

Toluene

Figure 4 illustrates the spatial distribution of toluene in autumn 2003 (4(a)) and in spring 2004 (4(b)). The concentrations are presented in parts per trillion (ppt).

The toluene concentrations do not exceed the Maximum Contaminant Level as mentioned above. Spatial analysis as illustrated in figure 4(a), shows that the pollution in autumn 2003 is accumulated at the same locations as benzene; at the eastern boundaries of the Military Airfield, at the southeastern side of the town of Aspropyrgos, and northeast of the Hellenic Refinery of Aspropyrgos (ELPE). However, the concentrations are much lower than benzene for both seasons. The interpolated maps demonstrate a potential spreading of toluene around the Hellenic Refinery. The pollution from toluene is low except a miscellaneous spot northeast of the Refinery of Aspropyrgos

As shown in figure 4(b), the concentrations of toluene during autumn are higher than the concentrations in spring. In spring 2004, there appears to be miscellaneous results with low toluene concentrations in groundwater northeast of the Hellenic Refinery installations.

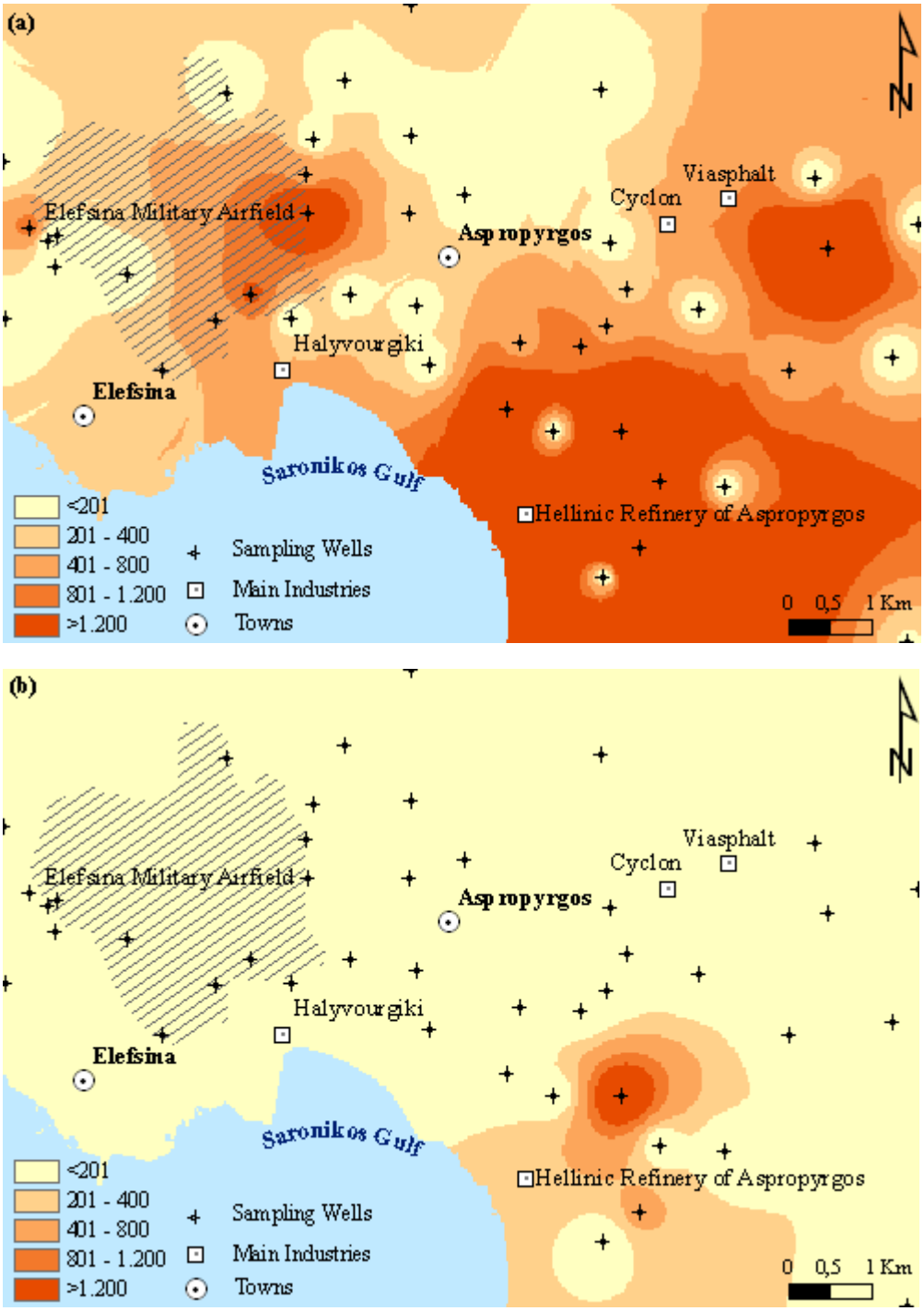

Figure 4. The spatial distribution of Toluene concentrations in groundwater (in ppt) in the Thriassio Field for the two sampling periods: autumn 2003 (a), spring 2004 (b)

Ethylbenzene

Figure 5 illustrates the spatial distribution of ethyl benzene concentrations in groundwater in autumn 2003 (5(a)) and in spring 2004 (5(b)). Concentrations of ethyl benzene are measured in parts per trillion (ppt).

In autumn 2003, the pollution from ethyl benzene is located in the eastern circumference of the Elefsina Military Airfield and northeast of the Hellenic Refinery, where it seems to cover a large area. The ethyl benzene plume appears to be more closely related to the toluene plume than the benzene plume.

In spring 2004, the concentrations are so low that pollution is considered negligible

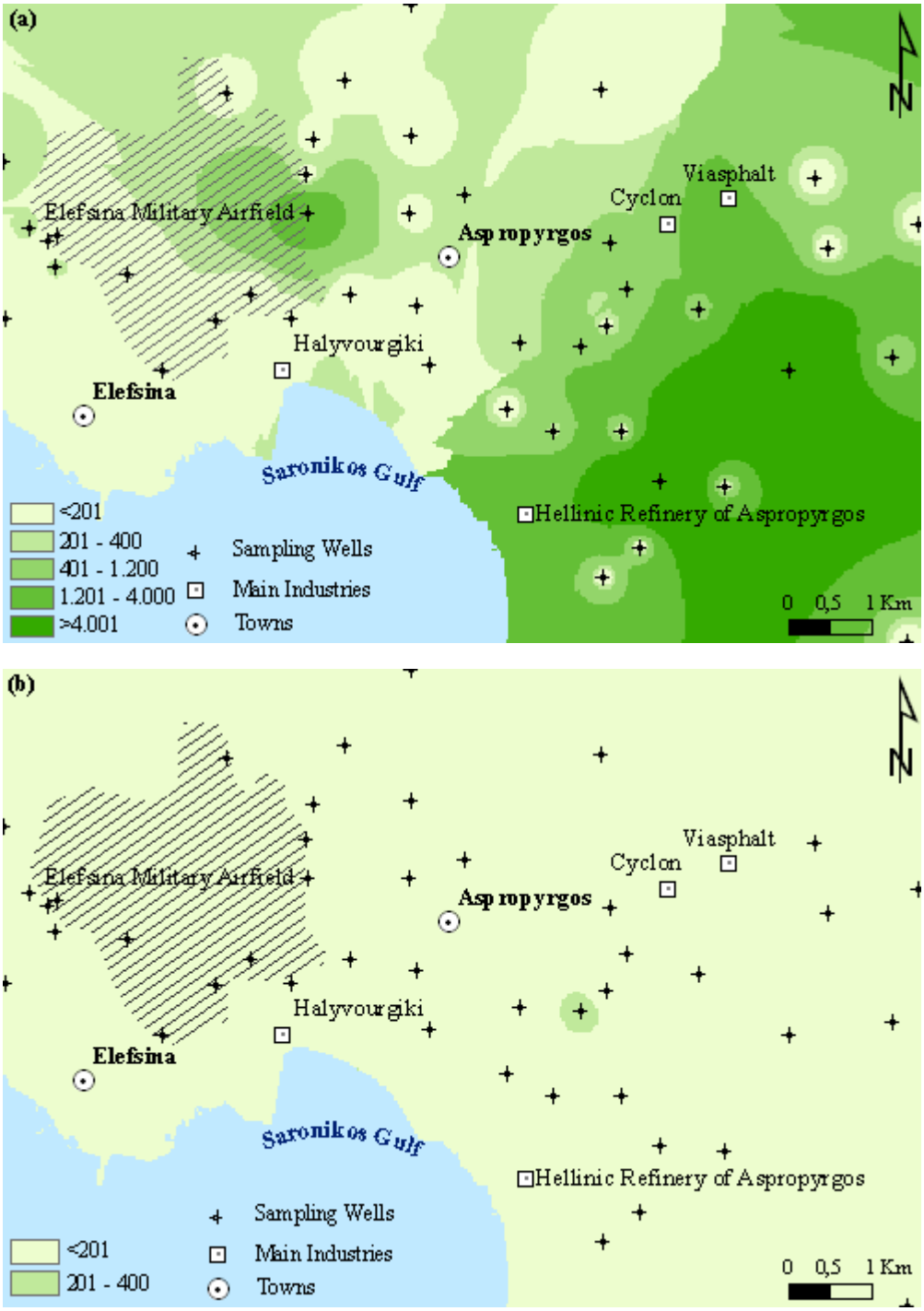

Figure 5. The spatial distribution of thyl-benzene concentrations in groundwater (in ppt) in the Thriassio Field for the two sampling periods: autumn (a), spring (b)

Xylenes

Figure 6 illustrates the spatial distribution of the concentration of total xylenes (o, m, p xylenes) in groundwater in autumn 2003 (6(a)) and in spring 2004 (6(b)). The values are presented in parts per trillion (ppt).

In autumn 2003, xylenes are observed mainly to the northeast the Hellenic Refinery and southeast of the town of Aspropyrgos. The Elefsina Military Airfield appears to be less polluted by xylenes than the other BTEX compounds. The shape of the pollution from xylenes is a little different than that of benzene, toluene and ethyl benzene. The pollution appears to flow towards the Saronikos Gulf, whereas this does not appear to be the case for benzene and

toluene. There is a plume of xylenes southeast of the town of Aspropyrgos, with a similar shape as that of benzene but less extensive.

In spring 2004, xylene pollution is significantly reduced, however, there is an accumulation southeast of the town of Aspropyrgos this contamination appears to continue to the Saronikos Gulf.

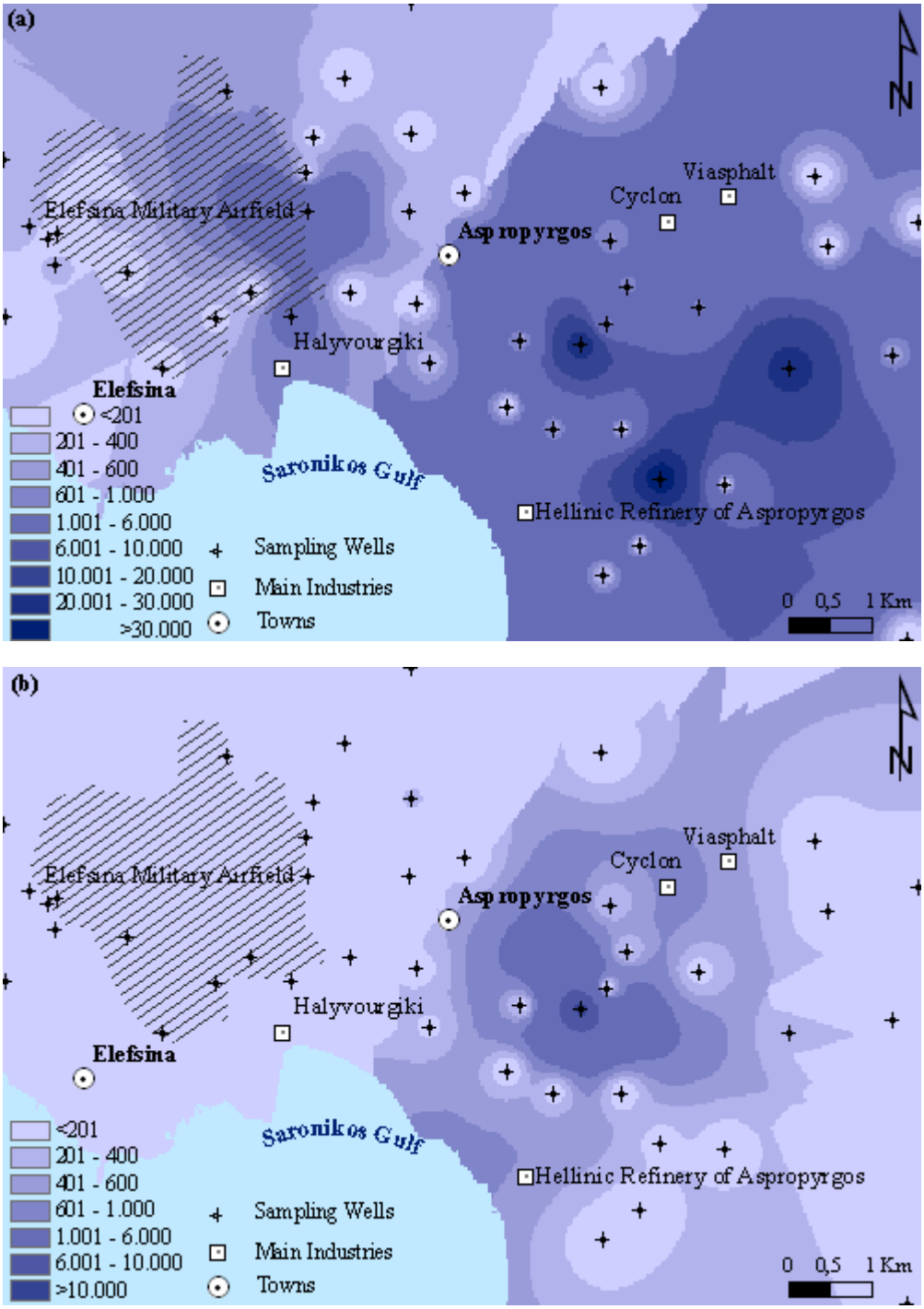

Figure 6. The spatial distribution of the concentration of o, m, p, Xylenes in groundwater (in ppt) in the Thriassio Field for the two sampling periods: autumn (a), spring (b).

CONCLUSIONS

The laboratory and spatio-temporal analysis of the results has lead to the following general conclusions:

- The level and extent of pollution from BTEX in the Thriassio Field appears to be seasonally related. In autumn, when the water table is at low level, there generally appears to be a higher concentration of the target pollutants;

- Concentrations of BTEX in spring are very low, which may be a result of a deficiency in rainfall and the uncontrolled pumping of groundwater in the summer months;
- There appears to be three polluted areas: one area is located southeast of the town of Aspropyrgos, another around the eastern boundary of the Elefsina Military Airfield and a third, northeast of the Hellenic Refinery of Aspropyrgos;
- In autumn 2003, four (4) values of benzene exceeded the Maximum Contaminant Limit, that is, the limit value above which immediate remediation is necessary. Hence, before any further study, it is advisable to proceed to remediation in these reported locations;
- The city of Elefsina is not polluted from BTEX although the city is located at the lowest part of the aquifer. Theoretically, the pollution should "track" the drainage network (flowing into Saronikos Gulf), and, thus pollution should impact the southern areas, near to the coastline. This conclusion suggests the existence of some hydrogeological particularities that are connected with the migration of the BTEX contamination in the aquifer. It may be assumed that apart from being dissolved into groundwater and following the general water movement, other mechanisms connected with specific geochemical conditions affect the compounds fate and transport;
- The GIS process suggests that the area close to the coastline is relatively clean, which may indicate a "flushing" of the seawater into the shallow aquifer;
- The concentrations of benzene were much higher than the other target analytes, and this suggests that much of the pollution is related to a petroleum source; and,
- The BTEX pollution across the Thriassio Field seems to stem from a "random" accumulation of petroleum products and is unlikely to be related to one source area or incident.

It is recommended that the BTEX pollution in the Thriassio Field be monitored for one more year (sampling in autumn and in spring) but also, in between the two seasons (one sampling in the summer and one in the winter) for a more detailed assessment of the temporal distribution of the pollution. Other pollutants, such as Polycyclic Aromatic Hydrocarbons (PAHs), organo-metals or other compounds of less or more priority connected with petroleum pollution may also be investigated. If further monitoring demonstrates that the "unexpected" or "random" pollution persists, the authorities of the relevant area should fully establish the polluting sources and take measures to prevent further environmental damage. The mechanisms and migration pathways relating to BTEX transport in the Thriassio Field will also be an interesting hydro-geochemical issue for further study.

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Corresponding author: Mrs Panayota Makri, National and Kapodistrian University of Athens, Panepistimioupolis, Zografou, Attiki, 157 84, Greece. Tel: +30 210 727 4178. Email: pmakri@geol.uoa.gr.

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