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Impact of intensive agricultural practices on drinking water quality in the EVROS Region (NE GREECE) by GIS analysis

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Abstract Chemical fertilizers are used extensively in modern agriculture, in order to improve yield and productivity of agricultural products. However, nutrient leaching from agricultural soil into groundwater resources poses a major environmental and public health concern. The Evros region is one of the largest agricultural areas in Northern Greece, extending over 1.5 million acres of cultivated land. Many of its drinking water resources are of groundwater origin and lie within agricultural areas. In order to assess the impact of agricultural fertilizers on drinking water quality in this region, tap-water samples from 64 different locations were collected and analyzed for the presence of nitrates $\left(NO_3^-\right)$, nitrites $\left(NO_2^-\right)$, ammonium $\left(NH_4^+\right)$, sulfate $\left(SO_4^{-2}\right)$ and phosphate $\left(PO_4^{-3}\right)$. These chemicals were selected based on the information that ammonium nitrate, ammonium sulfate and inorganic phosphate were the primary fertilizers used in local crop production. NO_3^-, SO_4^{-2} and PO_4^{-3} levels exceeding accepted values were recorded in 6.25, 4.70 and 9.38% of all sampling points, respectively. NO_2^- and NH_4^+ concentrations, on the other hand, were inside the permitted range. The data generated were introduced into a geographic information system (GIS) program for computer analysis and projection maps representing afflicted areas were created. Our results indicate a profound geographic correlation in the surface distribution of primary contaminants in areas of intensified agricultural production. Thus, drinking water pollution in these areas can be attributed to excessive fertilizer use from agricultural sources.

Keywords Agriculture · Chemical quality · Drinking water · GIS · Impact

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Introduction

Modern agriculture depends upon the addition of chemical fertilizers and pesticides in order to improve production methods. Synthetic fertilizers, in particular, increase yield and productivity of agricultural products by adding excess nutrients to agricultural soils. Nutrient run-off (leaching) from agricultural fields, however, has been shown to impact both aquatic and terrestrial ecosystems and degrade the quality of groundwater destined for human consumption (Horrigan et al. 2002; Gregory et al. 2002; Aelion and Conte 2004).

Such anthropogenic sources of drinking water contamination constitute a major problem in both developing and industrialized countries around the world (Nas and Berktay 2006; Camargo and Alonso 2006; Tilman et al. 2002). Moreover, groundwater contamination by pesticides and nitrates is an important epidemiological factor associated with the induction of various forms of cancer, reproductive and developmental toxicity and methemoglobinaemia (Horrigan et al. 2002; Fewtrell 2004; Avalanja and Bonner 2005). Assessing the impact of intensified agricultural practices on the regional scale is, thus, necessary in order to address important environmental and public health concerns.

The Evros region is one of the largest agricultural areas in northern Greece, extending over 1.5 million acres of cultivated land. Agriculture is practiced by the majority of local populations at the north and eastern borders, where most of the annual crop production takes place. Fertilizer use in this area has been extensive over the last 25 years (NSS 2006; Fytianos and Christophoridis 2004). Moreover, local farmers and agricultural experts have indicated that ammonium nitrate, ammonium sulfate and inorganic phosphate were the primary fertilizers used in production methods.

In this study the impacts of the intensive agricultural practices on drinking water quality in the region have been assessed using the concentration of primary chemical pollutants derived from the fertilizers as an index. A geographical information system (GIS) approach was undertaken, in order to generate spatio-temporal information regarding the contamination of drinking water resources in this region.

Material and methods

Study area and chemical analysis

The Evros region is one of the largest agricultural areas in Greece. About 1.5 million acres of land are, currently, exploited and major products marketed include wheat, corn, cotton, barley and sugar beet. Most of the agricultural areas in this region reside at the north/northeastern borders, where Erythropotamos and Ardas rivers form planes of fertile soil (Fig. 1). Another major agricultural area runs in parallel to the Evros river around the city of Feres in the southeast (Fig. 1). Both irrigation and drinking water supplies in these regions rely, mostly, on groundwater. In order to assess the impacts of intensive agricultural practices on drinking quality in this region, tap water samples from 64 different locations were collected and analyzed for the presence of nitrates $\left(NO_3^-\right)$, nitrites $\left(NO_2^-\right)$, ammonium $\left(NH_4^+\right)$, phosphate $\left(PO_4^{-3}\right)$ and sulfate $\left(SO_4^2\right)$. Samples were collected once every month, from each point, for a total period of 6 months (May–September 2006) and analyzed for the presence of chemicals: nitrates $\left(NO_3^-\right)$, nitrites $\left(NO_2^-\right)$, ammonium $\left(NH_4^+\right)$, phosphate $\left(PO_4^{-3}\right)$ and sulfate $\left(SO_4^{-2}\right)$ using standard spectrophotometric methods (APHA 1998). These chemicals were selected based on the information that ammonium nitrate, ammonium sulfate and inorganic phosphate were the primary fertilizers used by local farmers.

Geographic Information System (GIS) analysis

Coordinates of sampling points were recorded by a mobile GPS (Magellan eXplorist 500LE). The results of the chemical analysis (mean value per sampling point) were, then, used as input data in ArcGIS 9.2 (ESRI, San Diego, USA). Spatial analysis of drinking water contamination was performed by interpolation of sampling points by the algorithmic method

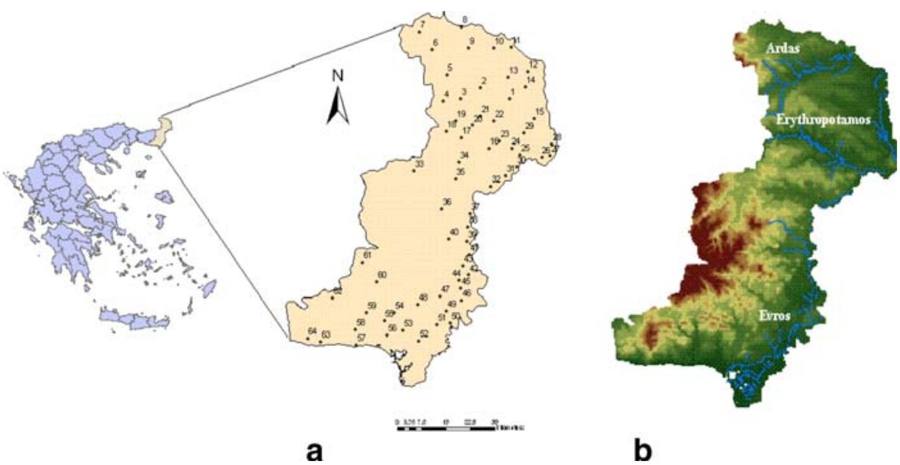

Fig. 1 **a** Map of Evros region (NE Greece) indicating the location of 64 sampling points. **b** Geophysical map of Evros region, indicating areas of high agricultural importance (around rivers Ardas, Erythropotamos and Evros)

Table 1 The results of the chemical analysis representing the mean concentration of nitrates $\left(NO_3^-\right)$, nitrites $\left(NO_2^-\right)$, ammonium $\left(NH_4^+\right)$, phosphate $\left(PO_4^{-3}\right)$ and sulfate $\left(SO_4^{-2}\right)$ in the drinking water supply of 64 sampling points in the Evros region (NE Greece)

Sample number	Location	NO_3^- (ppm)	NO_2^- (ppm)	NH_4^+ (ppm)	PO_4^- (ppm)	SO_4^- (ppm)
1	Lepti	18	0.0	0.01	0.95	67
2	Valtos	17	0.0	0.05	0.79	171
3	M. Doxipara	18	0.04	0.05	1.0	158
4	Zoni	39	0.05	0.04	1.07	229
5	Kyprinos	33	0.04	0.06	1.21	50
6	Pentalofos	14	0.03	0.03	1.0	176
7	Petrota	4	0.04	0.08	1.27	98
8	Dikaia	20	0.04	0.21	1.19	68
9	Spilaio	14	0.04	0.2	1.52	62
10	Kanadas	37	0.05	0.21	1.74	96
11	Kastanies	15	0.06	0.21	1.28	109
12	N. Byssa	12	0.03	0.19	1.14	68
13	Sterna	38	0.06	0.24	1.13	64
14	Sakos	10	0.08	0.31	1.33	78
15	Hemonio	9	0.16	0.2	0.95	82
16	Kyani	27	0.01	0.01	1.24	212
17	Giatrades	31	0.02	0.02	1.18	208
18	Metaxades	23	0.03	0.05	1.37	253
19	Ladi	47	0.03	0.07	1.39	210
20	Elafohori	71	0.13	0.06	1.27	308
21	Sitohori	19	0.05	0.07	1.33	75
22	Sitaria	57	0.05	0.08	2.45	59
23	Karoti	28	0.05	0.03	1.42	94
24	Ellinohori	27	0.05	0.03	4.16	111
25	Didymoteicho	24	0.13	0.05	5.99	108
26	Praggi	59	0.07	0.04	5.55	165
27	Petrades	212	0.06	0.04	1.72	286
28	Pythio	30	0.06	0.09	4.23	149
29	Thyrea	17	0.1	0.1	6.16	120
30	Psathades	16	0.18	0.07	5.64	98
31	Amorio	20	0.09	0.06	6.28	101
32	Lavara	12	0.05	0.03	2.77	120
33	M. Derio	4	0.05	0,0	2.87	58
34	Mauroklissi	13	0.03	0,0	3.75	66
35	Protoklissi	5	0.04	0,01	3.66	94
36	Giannouli	9	0.05	0,3	3.29	106
37	Soufli	13	0.03	0,0	2.74	120
38	Kornofolia	19	0.02	0.01	2.3	110
39	Lykofi	11	0.01	0.01	1.2	121
40	Dadia	18	0.03	0.08	2.42	91
41	Lagyna	5	0.02	0.11	2.62	83
42	Tyhero	5	0.01	0.02	1.2	105
43	Fylakto	6	0.01	0.01	1.3	123
44	Provatonas	8	0.03	0.04	1.4	100
45	Thymaria	9	0,02	0.0	2.3	95
46	Peplos	5	0.01	0.04	1.2	79
47	Itea	9	0.09	0.02	1.9	56
48	Melia	15	0.06	0.01	2.1	61
49	Ardanio	18	0.01	0.02	2.7	241
50	Poros	35	0.01	0.01	2.1	162
51	Feres	22	0.1	0.03	3.1	204

Table 1 (continued)

Sample number	Location	NO_3^- (ppm)	NO_2^- (ppm)	NH_4^+ (ppm)	PO_4^- (ppm)	SO_4^- (ppm)
52	Monastiraki	12	0.1	0.0	2.7	112
53	Loutros	18	0.06	0.0	0.31	47
54	Nipsa	3	0.03	0.1	0.6	90
55	Doriko	2	0.06	0.14	0.25	130
56	Anthea	13	0.04	0.1	0.42	145
57	Alexandroupoli	11	0.02	0.04	0.6	122
58	Palagia	9	0.05	0.01	0.78	45
59	Avantas	6	0.1	0.1	0.9	55
60	Aisymi	2	0.03	0.0	0.2	41
61	Leptokaria	3	0.01	0.0	0.5	30
62	Kirki	3	0.03	0.0	0.3	67
63	Makri	2	0.05	0.12	0.4	122
64	Dikella	9	0.03	0.5	0.15	245

'Inverse Distance Weighted' (IDW). Associated maps representing afflicted areas were created and mathematical formula called the 'water pollution index' (WPI) was devised (Lee et al. 2006), in order to assess the combined impact of the three most common chemicals $\left(NO_3^-, PO_4^{-3}, SO_4^{-2}\right)$ in drinking water. This formula is given below:

$$\mathrm{WPI}i = \frac{\sum \frac{C_N}{C_{N'}} + \frac{C_P}{C_{P'}} + \frac{C_S}{C_{S'}}}{3}$$

Where i=sampling location. C_X=$_{N,P,S}$ is the measured concentration of N = NO_3^-, P = PO_4^{-3} and S = SO_4^{-2} at each sampling point and $C_{X'}$=$_{N',P',S'}$ is the maximum permitted concentration for these chemicals based on EC standards (EEC 1998; i.e. 50 mg/l for NO_3^-, 5 mg/l for PO_4^{-3} and 250 mg/l for SO_4^{-2}).

Results and discussion

The geographical location and distribution of 64 sampling points in the Evros region (NE Greece) is indicated in Fig. 1. Table 1 shows the mean concentration of nitrates $\left(NO_3^-\right)$, nitrites $\left(NO_2^1\right)$, ammonium $\left(NH_4^+\right)$,

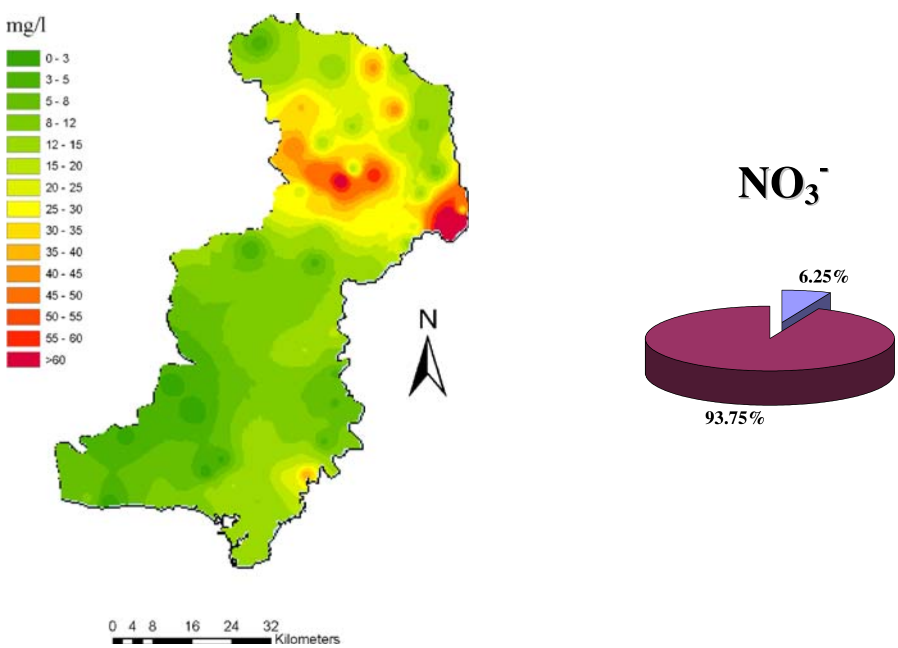

Fig. 2 GIS map indicating the spatial distribution of nitrates $\left(NO_3^-\right)$ in the Evros region

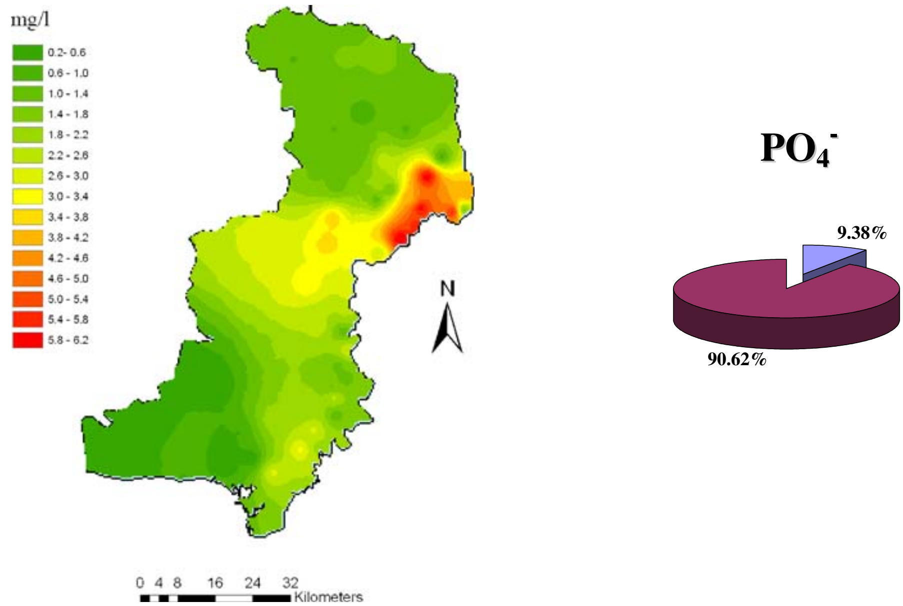

Fig. 3 GIS map indicating the spatial distribution of phosphates $\left(PO_4^{-3}\right)$ in the Evros region

sulfate SO_4^{-2} and phosphate $\left(PO_4^{-3}\right)$. Figures 2, 3 and 4 represent the resulting maps corresponding to the three most abundant chemical pollutants: nitrate, phosphate and sulfate, respectively.

Nitrates

Nitrate concentrations in the samples ranged from 2 to 212 ppm. Four out of 64 samples (6.25%) contained nitrate concentrations exceeding 50 ppm, which is the EC drinking water limit (EEC 1998). The mean nitrate concentration of all samples was 20.9 ppm. However, 17.2% of samples exhibited nitrate values between 25 and 50 ppm which was above the guided level of 25 ppm (EEC 1980). This level was proposed in order to reduce the risk of methemoglobinaemia in children (Fewtrell 2004). Samples taken from the area around Erythropotamos river (16–28), which is the most inten-

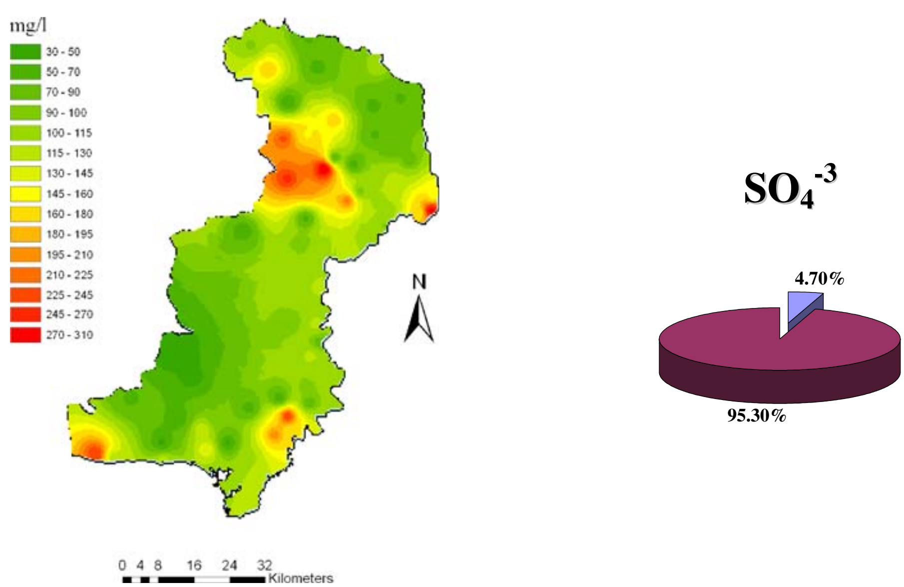

Fig. 4 GIS map indicating the spatial distribution of sulfates $\left(SO_4^{-3}\right)$ in the Evros region

sively cultivated area in the Evros region were especially high in nitrates, with a mean value of 50.4 ppm. On the other hand, some of the lower values for nitrates were recorded in the southern parts of the region that are predominantly urbanized. Hence, samples 54 to 64 had a mean nitrate value of 6.3 ppm.

Phosphates

Phosphate concentrations ranged from 0.2 to 6.28 ppm. Approximately 7.8% of samples contained phosphate concentrations exceeding the EC recommended value of 5 ppm (EEC 1998). As it can be seen in Fig. 3, the geographical distribution of phosphates is most prominent in the western-most part of Erythropotamos river. Samples 23 to 31, in particular, had a mean phosphate value of 4.97 ppm, which is just below the recommended EC limit.

Sulfates

Sulfate levels exceeding the recommended value of 250 ppm were recorded in 4.7% of all sampling points (Fig. 4). Sulfate pollution of drinking water was most prominent in the eastern part of Erythropotamos river, as well as at certain foci in the central east and southwest. The highest sulfate values were recorded in the region concerning sampling points 16 to 20 (concentration range: 208 to 308 ppm, mean value 238.2 ppm). This may reflect selective application of sulfur containing fertilizers in the area, in order to meet specific agricultural demands.

Water Pollution Index (WPI)

Differences in pollution schemes may represent a diversification of chemicals in the aquifer in terms of bioavailability, as well as changing patterns of fertilizer use with respect to crop demand. In order to assess the combined impact of the three most abundant chemicals (nitrates, phosphates and sulfates) in drinking water quality in this region, a mathematical formula called the water pollution index (WPI) was devised (Lee et al. 2006). Using these data, a WPI map of Evros region has been created. As can be seen in Fig. 5, the distribution of drinking water contaminants, correlates highly with the most intensively exploited areas for agriculture in this region. Hence, the Erythropotamos river area in the north and the Evros river area in the southeast were the most heavily affected areas in terms of drinking water pollution.

Between 1960 and 2000, global use of nitrogen (N) and phosphorus (P) fertilizer has increased about 8- and 3.5-fold respectively (Tilman et al. 2002). Today, only 30–50% of applied N-fertilizer and ~45% of P-fertilizer is taken up by crops (Cassman 1999). A significant amount of these nutrients is lost from agricultural fields, due to diminishing returns. Hence, such non-point nutrient losses are a primary determinant of groundwater contamination.

Fertilizer use in Greece has increased drastically between 1961 and 1990. During this period, total use of agricultural fertilizers has increased from 158,724 to 696,000 tons/year, exhibiting an average annual 0.15-fold rise (FAOSTAT 2007). Since the introduction of directive 91/976 (EEC 1991), regarding the protection of groundwater resources from nitrates, there has been a significant reduction of total fertilizer use at the national level. However, the impact of chronic contamination of aquifers lying beneath agricultural lands can still be observed as this study indicates.

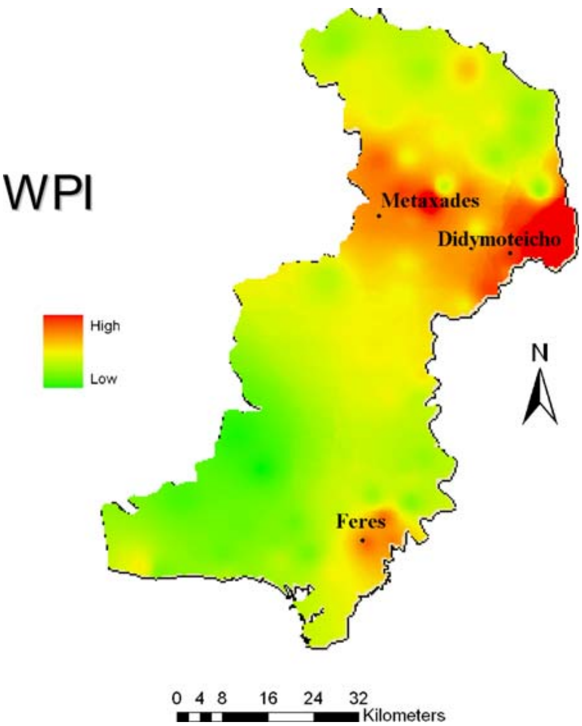

Fig. 5 GIS map indicating drinking water pollution (WPI) in the Evros region

Using the combined information for the three most common chemical contaminants, a drinking water pollution (index) map of the area has been created. The specific attributes of each area were interrelated in this scheme with respect to agricultural production. It appears that the water pollution index (WPI) is higher in areas where agriculture is practiced more intensively. This has led to the formulation of the hypothesis that agriculturally-derived pollution of drinking water resources in these areas can have a direct, detrimental impact on drinking water quality.

Intensive agricultural practices compromise environmental integrity and public health. Nitrate levels, in particular, must be strictly regulated. Several epidemiological studies have shown a significant risk probability between elevated nitrate concentrations in drinking water and a battery of pathological states ranging from reproductive anomalies and human cancer, to endemic nephropathy and methemoglobinaemia (De Roos et al. 2003; Fewtrell 2004; Manassaram et al. 2006; Niagolova et al. 2005). These findings, thus, highlight the need for more sustainable methods of production.

Conclusions

The aim of this study was to generate geographical information regarding the distribution of drinking water contaminants in the Evros region (NE Greece) and analyze its relationship to agricultural practices at certain key locations. This was done by the elaboration of a geographic information system (GIS) approach. GIS provides a valuable tool for environmental analysis and has been used, successfully, in the past to integrate spatiotemporal information regarding environmental toxicology and public health (De Paz and Ramos 2002; Lake et al. 2003). Using this approach we have managed to generate a water pollution map of the area. Our results indicate the presence of high levels of nitrates (as well as sulfates and phosphates) in areas of intensified agricultural production. These findings are in accordance with several studies contacted in agricultural areas around the world (Barrett et al. 1998; Gelberg et al. 1999; Yang et al. 2004). Thus, it can be argued that the deterioration of drinking water quality in these regions can be directly linked to excessive fertilizer use from agricultural sources. Moreover, novel and previously unassigned nitrate vulnerable zones (NVZ) in the Evros region have been mapped in great geographical detail. This information could be used to prevent public exposure to toxic substances through water contamination by limiting the supply of contaminated water in heavily affected areas.

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