ENVIRONMENTAL ASSESSMENT OF GROUNDWATER NITRATE POLLUTION FROM AGRICULTURAL WASTES AND FERTILIZERS IN CENTRAL GREECE WATERSHEDS USING REMOTE SENSING AND GIS

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ABSTRACT

Groundwater has been considered as an important source of water supply due to its relatively low susceptibility to pollution in comparison to surface water, and its large storage capacity. For most people in the European Union (EU), access to clean water in abundant quantities is taken for granted. It is not realized, however, that many human activities (diffuse pollution from agricultural sources) put a burden on water quality and quantity. The objectives of this paper are to document and evaluate regional trends and occurrences of nitrate in the groundwater of agricultural watersheds in Central Greece. A land use survey and water quality survey was performed in 2004 and ground water samples from various wells were collected in the time interval April - June and analysed in laboratory. The pH of the samples was measured by a pH electronic meter with a sensor probe. For the analyses in the laboratory in nitrate (NO_3^-) and in NO_3-N, was used method 8039 (Procedure Code N5) or Cadmium Reduction Method that is suitable for water, wastewater and marine water (USEPA 1980), by the use of a laboratory instrument (Spectrophotometer) with sensors controlled by a microprocessor. Finally, a general research on cultivators' practises, agricultural wastes disposal and fertilizers use was conducted. Also with the use of GIS and Remote Sensing tools, a hydrological analysis was conducted and it was studied from satellite images the correlated vegetation, (types and extend of agricultural plantations). Also, a model calculation was performed on wastes and fertilizers loads of the study area in conjunction with remote sensing acquired satellite images and finally the nitrates pollution of an agricultural ecosystem watershed was studied and assessed, based on the above.

Results showed that GIS and Remote Sensing are significant tools that help to depict the groundwater nitrate pollution and to identify contaminated areas. Also, GIS based maps of nitrogen pollution from agricultural sources (wastes, fertilizers, etc) are characterised by remarkable spatial variability, and in many cases, results of the nitrate concentrations were found above the EU suggestive limit of 25 mg/l and more important, in other cases they were found above the EU maximum limit of 50 mg/l. Based on the results of research, Remote Sensing analysis and GIS modelling and mapping with the nitrates contamination of the groundwater, constitutes an important tool of research that is offered for environmental policy measures advisement, proposal and consideration of environmental management practices, aiming at the protection and sustainable management of water resources and at farm economy (fertilizers' reduction).

Key words: Groundwater nitrate pollution, Remote Sensing analysis, GIS, watershed.

1. INTRODUCTION

Nitrogen (N) is a vital nutrient to enhance plant growth [1], [2], [3], [4] so the presence of nitrates in soil is necessary for their growth. The greatest use of nitrates is as a fertilizer for agricultural use. However, excess soil nitrates can contaminate water supplies, creating a potential health concern [4]. Nitrate (NO_3) is the most common pollutant found in shallow aquifers and groundwater due to both point and non-point sources [5]. Aquifers are an important source of drinking water and these sources are vulnerable to contamination [6]. High nitrate levels in water may be encountered in agricultural areas, often in wells located near a long established barn site. Nitrates can leach from the soil into underground aquifers, contaminating well water. The extent of nitrate contamination, and how quickly it occurs, depends both on soil type and on depth of the water source. Nitrates can leach more easily in light sandy soils than in clay-based soils [7], [4].

Groundwater has been considered as an important source of water supply due to its relatively low susceptibility to pollution in comparison to surface water, and its large storage capacity [8]. Agricultural practices can result in non-point source pollution of ground water [9], [2], [4]. Nonpoint sources are often responsible for nitrates and pesticides in groundwater. The extensive use of fertilizers on row crops is considered as a main source of nitrate leaching to ground water particularly in sandy soils [10], [11].

With non-point sources (NPS), ground water quality may be depleted over time due to the cumulative effects of several years of practice [12], [13]. Non-point sources of nitrogen from agricultural activities include fertilizers, manure application, and leguminous crops [4]. Elevated nitrate concentrations in ground water are common around dairy and poultry operations, barnyards, and feedlots [14], [15].

Nitrates have a high potential to migrate to shallow aquifers and groundwater because they are very soluble and do not bind to soils. Also, because they do not evaporate, nitrates are likely to remain in contaminated water until consumed by plants or other organisms. Contamination is more common in shallow wells than in wells drilled into deeper aquifers. Heavy rains, irrigation methods and flooding also affect the amount of nitrate that reaches both ground and surface water [4], [16]. There are two main concerns arising from the presence of nitrates in water:

- 1. High nitrate levels in rivers and lakes can increase algae growth, degrading habitat for fish, other aquatic organisms, and wildlife.
- 2. High nitrate levels in drinking water can have adverse effects on human health.

The EU water framework directive (2000/60/EC) aims to get polluted water clean again, and to ensure that clean waters are kept clean [17], [4].

Despite the adoption of the Nitrates Directive (91/676/EC) throughout the European Union by Member States in 1991 [18], [19], the nitrate concentrations of many rivers in Greece have continued to increase.

2. EXPERIMENTAL PART

2.1. Materials

Data and samples collection: A study was performed in the water region of Central Greece, on water quality. An agricultural land and water quality survey was performed and water samples from various wells were collected and analysed in laboratory. Various samples of groundwaters were collected on different dates in 2004.

Also, remotely sensed data and standard topographic maps of scale 1:50,000 have been used as data sources, together with ground truth studies, which have also been carried out. For the analysis of land-use/land cover vegetation and other changes, data from the satellite sensor ETM+ (satellite LANDSAT 7 ETM+) [20] from 1999, have been used together with data from ASTER sensor (satellite EOS-1 (former TERRA)) [21] acquired in the year 2004. The technical features of satellite sensor data and images that were used are given in Table 1.

Table 1. *Information about satellite sensors data used in the study.*

SN	SATELLITE Image	Row/ Path	Acquisition Date	Number of Bands	Spectral Range [microns]	Spatial Resolution [m]
1.	LANDSAT 7 ETM+	183/033	28-07-1999	Total 9.		
				6	0.45-2.35	30
				2(Thermal IR)	10.40-12.50	60
				1 Pan	0.52-0.90	15
2.	EOS-1 (ASTER)	Alternative	22-05-2004	Total 14.		
				3 VNIR	0.52-0.86	15
				6 SWIR	1.6-2.43	30
				5 TIR	8.125-11.65	90

2.2. Instruments-devices

Regarding groundwater sampling, two GPS (Global Position System) devices were used to log spatial data of the various locations, where water samples from various wells were collected.

In the countryside, they were measured with a portable instrument the following physiochemical parameters: the temperature of water, the pH and the electrical conductivity (EC). For the analyses in the laboratory of the nitrates ions (NO_3^-), the nitrate nitrogen (NO_3-N) and ammoniac ions (NH_4^+), it was used a laboratory instrument (Spectrophotometer) controlled by a microprocessor, with sensors that were operated in wavelength of 500 nm (Hach, DR3000).

2.3. Methods

a) Data and groundwater samples collection: An agricultural land and water quality survey was performed and groundwater samples from various wells were collected and analysed in laboratory. Groundwater sampling was conducted to in order to provide information on the condition of subsurface water resources in Nembeglrioti stream watersheds region. Water samples were collected in the same farming period of 2004 from 37 sites.

b) Hydrolithological recognition and interpretation: Observations on the spot and use of the Geological map 1:50.000, Sheet: Nikaia Larissas.

c) Hydrochemical research and groundwater samples management: The samples were stored in fridge to avoid mineralization before the laboratory analyses. In the countryside, they were measured with a portable instrument the following physiochemical parameters: the temperature of water, the pH and the electrical conductivity (EC). In the laboratory of Mineralogy-Geology of Agricultural University of Athens were determined the nitrates ions (NO_3^-), the nitrate nitrogen (NO_3-N) and ammoniac ions (NH_4^+). For the analyses in the laboratory in nitrate (NO_3^-) and in NO_3-N, was used method 8039 (Procedure Code N5) or method of reduction of cadmium

(Cadmium Reduction Method) that is suitable for water, wastewater and marine water [22], by the use of a laboratory instrument (Spectrophotometer) controlled by a microprocessor.

Finally, a general research on cultivators' practises was conducted in the study area.

***d) GIS development-Implementation of geodatabases, remotely sensed images and parametric maps**:*

It was designed and developed a computer digital database for the study area, which contained various matrixes with the spatial and attribute data of the area and of the laboratory results, the remotely sensed images, the NDVI map and the parametric maps. The geographic information system (GIS) offers the possibility of structured data management and access [23], [24], [25]. Within GIS, objects are being built by linking spatial data (points, lines or polygons that are defined by geometry and topology) with semantic information. The GIS can be used to answer different queries depending on the data stored in it and allows also their analysis and export of further knowledge from the data set [4]. ArcGIS v9.1 software, complete with the Spatial Analyst software extension, running on an Intel-PC was used [26] for all GIS work and ERDAS Imagine v9.1 software, was used for all remote sensing work described in the present study. This software allowed the integration, implementation and analysis of vector and raster data formats.

The objectives of the present study are to document, evaluate and map regional trends and occurrences of nitrate in the groundwater of agricultural watersheds in Central Greece by environmental assessment of groundwater nitrate pollution from agricultural wastes and fertilizers using remote sensing, GIS, GPS, and in situ measurements.

3. RESULTS-DISCUSSION

The study area of the Kranonos, Nikaia and Platikampos Perfectures, (Larissa Region) is located 8 km south of Larissa city (Thessaly plain in Central Greece) and is illustrated in figure 1.a. The produced digital elevation model (DEM) displayed an elevation variation above mean sea level between 51.09 m to 349.31 m over the study area. The height increases north to south, west to east and northeast to southwest (figure 1.a).

The ISODATA unsupervised classification and the supervised classification of the satellite images (figure 1.b) were performed along with the use of ground truth GPS data and aerial photos in order to study the land changes/land cover vegetation with better accuracy, and resulted in final classification maps with land cover vegetation classes. The classification maps showed that wheat, maize, cotton and sugar beets are the main crops of the area. Image classification accuracy for the years 1999 and 2004 was satisfactory enough and varied between 81-94%.

In general, what makes GIS different from other kinds of computer mapping systems is that the attribute data and spatial information are always linked and processed jointly in GIS [4], [21], [22]. From the hydrological and hydrochemical analysis that was conducted, several valuable information and GIS maps were derived. In figure 2.a is depicted the flow direction of surface water in a GIS map and figure 2.b shows the water flow direction coding. Hydrological analysis of the study area with the use of the above mentioned GIS maps derived watersheds delineation areas and resulted finally in definition of seventeen watersheds (figure 3.a).

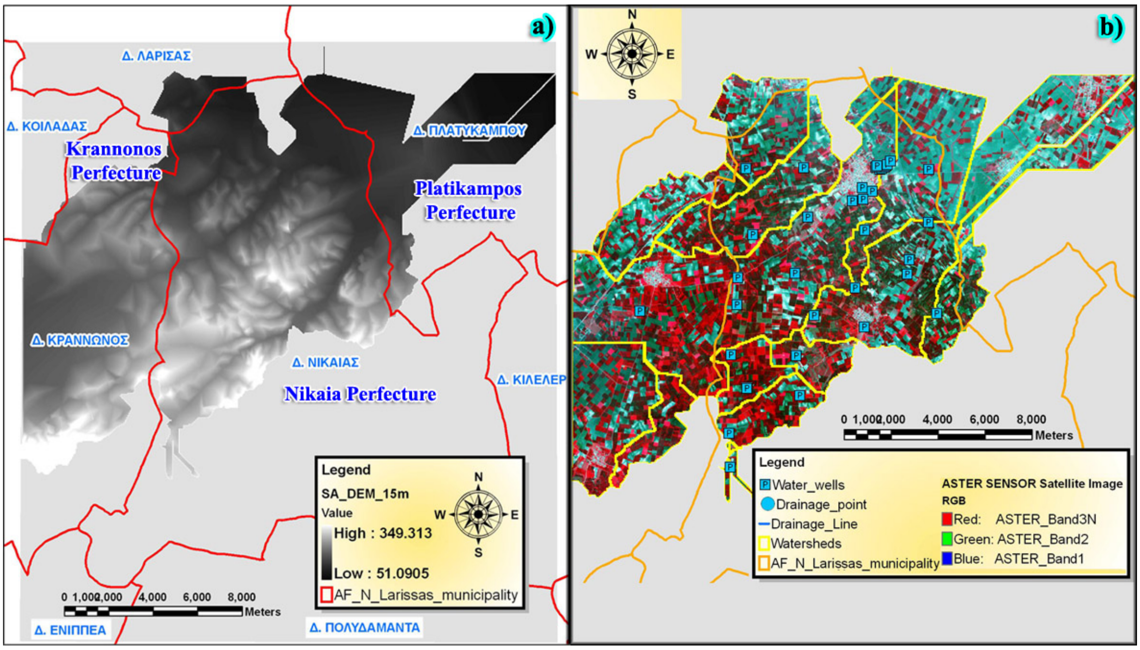

Figure 1. *a) Digital Elevation Model (DEM) of the study area. b) Sensors ASTER satellite image of 2004 with shape of the study area derived from the original path/row satellite image showing the study area in Central Greece.*

Also, in figure 3.b, are depicted the watersheds delineation areas with their Hydro Identification Numbers (HID), along with drainage lines and the drainage point of the entire area, overlaid to digital elevation model. Informations about the watershed areas (figure 3.a) and length of the watersheds are presented in table 2.

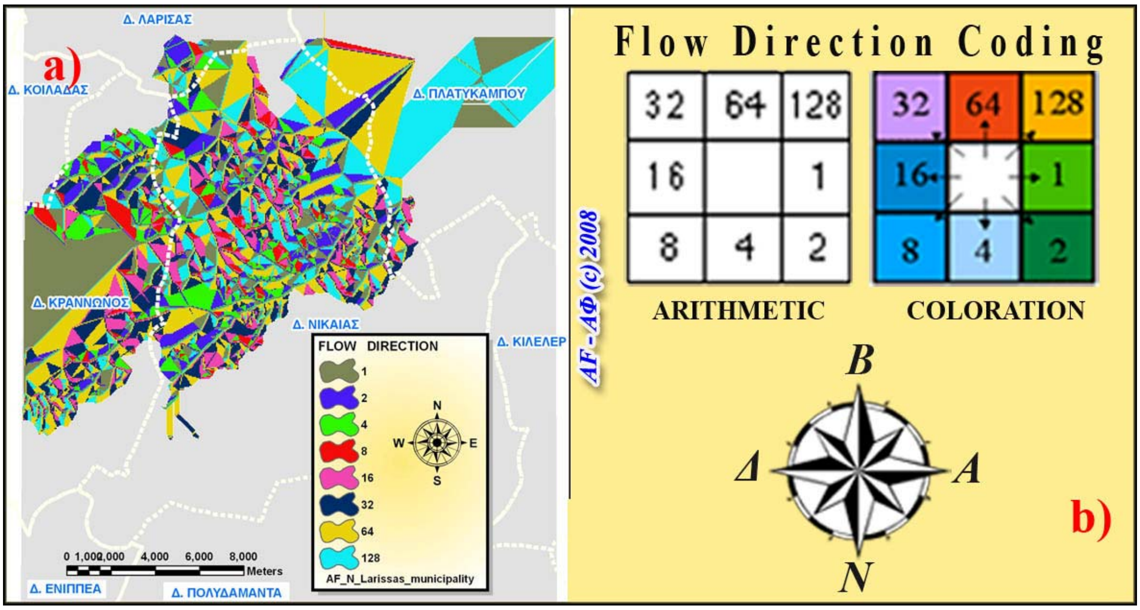

Figure 2. *a) Flow Direction Model of the study area. b) Flow Direction Coding.*

Water quality depends on factors dealing with soil genesis, climatic factors as well as human activities. Water sampling and spatial data were processed by computer processing and GIS methods. At the phase of processing they sustained suitable transformation so that they were formed and impressed spatial, giving the corresponding zones of nitrate (NO_3) variability to the groundwater of the study area.

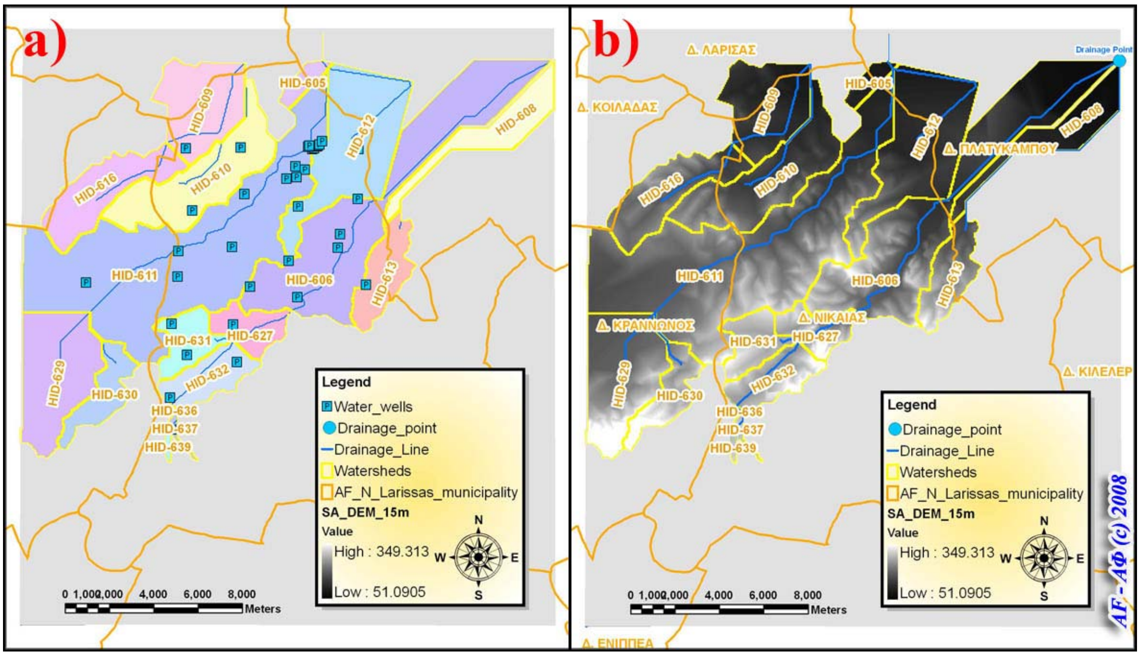

Figure 3. *a) Watersheds and water wells of the study area. b) Watersheds delineation areas and HID, drainage lines and drainage point of the entire area, overlaid to DEM.*

Table 2. *Information about the watersheds of the study area, which were derived from hydrological analysis and the number of the corresponding wells.*

SN	Watershed Shape	Watershed Hydro ID	Watershed area [ha]	Watershed length [m]	Number of Wells
1.	Polygon	605	234.00	11900.00	0
2.	Polygon	606	3779.50	56800.00	6
3.	Polygon	608	949.50	30300.00	0
4.	Polygon	609	1402.75	19200.00	1
5.	Polygon	610	1834.00	33700.00	2
6.	Polygon	611	6084.00	65600.00	12
7.	Polygon	612	2316.75	32100.00	9
8.	Polygon	613	841.75	41500.00	1
9.	Polygon	616	1241.00	25500.00	0
10.	Polygon	627	554.75	14000.00	1
11.	Polygon	629	1810.75	21900.00	0
12.	Polygon	630	649.25	23300.00	0
13.	Polygon	631	588.50	15500.00	2
14.	Polygon	632	742.00	17700.00	2
15.	Polygon	636	11.75	2100.00	0
16.	Polygon	637	63.25	7100.00	0
17.	Polygon	639	53.50	5100.00	1
		Total	23157	423300.00	37

The results of groundwater nitrate concentrations GIS mapping for the Nembeglrioti stream watersheds appear in figure 4.a. The nitrate concentration in water resources it was found that it had a spatial variability which was fluctuated between 18.6 to 210.9 mg/l in the various nitrate classes. A classification on the water Nitrate-concentration GIS map was performed and the result was one GIS map with the nitrate delineation zones of the area with five classes (figure 4.b.).

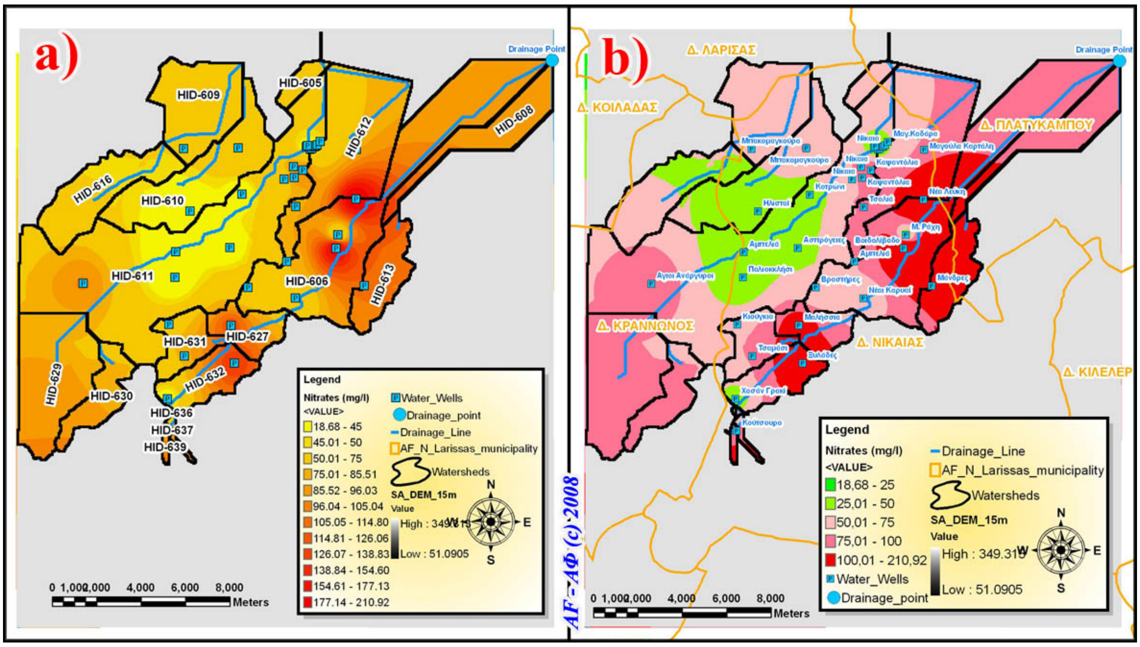

Figure 4. *a) GIS map of nitrate-NO_3 (mg/l) variability of the groundwater of the 17 watersheds delineation areas. b) GIS map of the study area showing the zones of nitrate groundwater pollution.*

As illustrated in figure 4.b. five main zones of nitrate concentration in water resources of the seventeen watersheds were distinguished:

- The first zone (light green colour) which covers a small area of one watershed where nitrate concentration ranged between 18.68 to 25.00 mg/l. These low concentrations indicated that the risk of which is depicted by the light green colour in GIS map in figure 4.b, originate from an area close to Nikaia. These area exhibit low pollution risk.
- The second zone (green colour) which covers a large area of two watersheds where nitrate concentration ranged between 25 to 50 mg/l. These medium scale concentrations indicated that the risk of which is depicted by the green colour in GIS map, originate from the areas close to Asprogies, Ampelia, Ilistai, Palaioklissi, Kotroni, Nikaia and Chasan Graki. These areas exhibit medium pollution risk and measures should be taken to mitigate this problem such as reduction in N fertilizers, rational water management, use of advanced irrigation methods (drip irrigation etc) and effective fertigation systems (for fertigation accuracy and fertilizer economization) and probably legislative measures.
- The third zone has been characterized as zone of high pollution risk (light pink colour) where concentration of nitrates oscillates between 50 and 75 mg/l and

originates from the areas close to Koutsouro, Kioungia, Ampelia, Chasan Graki, Vrastires, Mpakomagoura, Nees Karies, Kapsantolia, M. Raxi and Nikaia.

- The fourth zone has been characterized as zone of very high pollution risk (pink colour) where concentration of nitrates exceeds 75 mg/l with maximum 100 mg/l and originates from the areas close to Agioi Anargyroi, Tsamasi, Malissia, Ampelia, Tsolia, Nees Karies, Kapsantolia, M. Raxi, Magoula Kartali and Nikaia.
- The fifth zone has been characterized as zone of excessive pollution risk (red colour) where concentration of nitrates exceeds 100.0 mg/l with maximum 210.9 mg/l and originates from the areas close to Xilades, Malissia, Voidolivado, Mandres, Nea leyki and Koutsouro.

Accurate quantification of nitrate leaching is difficult. Nitrate leaching from the soil zone is a complex interaction of land use, on-ground nitrogen loading, ground water recharge, soil nitrogen cycle, soil characteristics, and the depth of soil [4]. Considering the high values of N mineralization, in conjunction with the agriculture dominated watersheds which increases the potential pollution risk, it is obvious that N fertilization should be reduced, effective irrigation and hydro fertilization (fertigation) systems should be used in order to protect the environment and the water resources of the region. The gradual orientation of the Common Agricultural Policy to take greater account of environmental issues contributes to the purposes of the Nitrates directive. A CAP more oriented towards quality rather than quantity, encouraging extensive cropping or breeding, "buffer" natural areas and accurate balanced fertilization, can further contribute to these purposes. Controlling nitrate emission is still primarily the task of transposition and implementation of the "Nitrate" Directive. Cost-efficiency studies on preventive measures should also be encouraged, in order to focus action programmes and practice changes towards the most efficient one.

Based on the results of research, Remote Sensing analysis and GIS modelling and mapping with the nitrates contamination of the groundwater, constitutes an important tool of research that is offered for environmental policy measures advisement, proposal and consideration of environmental management practices, aiming at the protection and sustainable management of water resources and at farm economy (fertilizers' reduction).

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