Ground water nitrate pollution from agricultural sources in agriculture-dominated watersheds

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Abstract

Diffuse pollution of water resources from agricultural sources is a major environmental issue both in the European Union and abroad. Water for drinking and agricultural use, high in nitrate is potentially harmful to human and animal health. Nitrate-(NO_3) is the most common pollutant found in shallow aquifers due to both point and non-point sources and it is a naturally occurring form of nitrogen which is very mobile in water. It is essential for plant growth and is often added to soil to improve productivity. However, nutrients released in surface and ground waters from cultivated fields and livestock production are the main source of concern, together with pesticides.

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. An agricultural land and water quality survey was performed and water samples from various wells were collected and analysed in laboratory. A hydrological analysis was conducted and several valuable information and GIS (Geographic Information Systems) maps were derived. These GIS maps were used to the extended hydrological analysis to derive watersheds delineation areas which resulted in seven watersheds. Also with the use of GIS and Remote Sensing tools, the nitrates pollution of an agricultural ecosystem in agriculture-dominated watersheds and the correlated vegetation cover was studied.

Results showed that nitrogen pollution from agricultural sources is characterised by remarkable spatial variability, depending on the interplay of the effects of human driving forces (land use, agricultural demands and activities) with environmental variables (climate, soil and topography). These phenomena differ in their scale and spatial features, which is a factor that should be accounted for when designing and implementing policy measures and management practices.

Keywords: Water nitrate pollution, Watershed, GIS, Remote Sensing, Agriculture, Nitrogen, Hydrological analysis.

1. Introduction.

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 (US EPA, 1985). Aquifers are an important source of drinking water and these sources are vulnerable to contamination (Solley et al., 1990).

Nitrogen (N) is a vital nutrient to enhance plant growth (Delgado, 2001; Delgado and Shaffer, 2002; Follett and Delgado, 2002; Filintas, 2005) so the presence of

nitrates in soil is necessary for their growth. However, excess soil nitrates can contaminate water supplies, creating a potential health concern (Filintas, 2005).
Nitrate (NO_3) is the most common pollutant found in shallow aquifers and groundwater due to both point and non-point sources (Postma et al., 1991). The greatest use of nitrates is as a fertilizer for agricultural use.

Agricultural practices can result in non-point source pollution of ground water (Hall et al., 2001; Delgado and Shaffer, 2002; Filintas, 2005). Nonpoint sources are often responsible for nitrates and pesticides in groundwater. 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 (Dioudis et al., 2003; Filintas, 2005). The extensive use of fertilizers on row crops is considered as a main source of nitrate leaching to ground water particularly in sandy soils (Hubbard and Sheridan, 1994; Filintas, 2003).

With non-point sources (NPS), ground water quality may be depleted over time due to the cumulative effects of several years of practice (Addiscott et al., 1992; Shilling and Wolter, 2001). Non-point sources of nitrogen from agricultural activities include fertilizers, manure application, and leguminous crops (Filintas, 2005). Elevated nitrate concentrations in ground water are common around dairy and poultry operations, barnyards, and feedlots (Hii et al., 1999; Carey, 2002). Unfortunately, it is difficult to predict NPS pollution in shallow aquifers and in groundwater due to agricultural activities because numerous factors including soil, climate, crop, rate and timing of pesticide and nutrient applications, irrigation methods and fertilizer system efficiency (Filintas et al., 2006) and tillage affect the concentration and movement of Nitrates and NPS pollutants in soil and in groundwater (Filintas, 2005).

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 (Filintas, 2005). 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.

Nitrogen and Phosphorus will certainly appear as priority polluters in many E.U. watersheds, as promoting cyanophytes (blue algae) problems in lakes and dams, macrophytes and dinoflagellates impairing tourism or aquaculture in coastal waters, etc. Efficiency of investment in preventive measures, on agricultural pressures and practices, or on domestic and industrial discharges, will have to be evaluated and compared (European Commission, 2002).

- 2. High nitrate levels in drinking water can have adverse effects on human health.

1.1. Health effects from nitrates pollution in groundwater.

The health effects from nitrates are dissociated in two categories:

a) Short-term: Excessive levels of nitrate in drinking water have caused serious illness and sometimes death. The serious illness in infants is due to the conversion of nitrate to nitrite by the body, which can interfere with the oxygen-carrying capacity of the childrens blood. This can be an acute condition in which health deteriorates rapidly over a period of days. Symptoms include shortness of breath and blueness of the skin.

b) Long-term: Nitrates and nitrites have the potential to cause the following effects from a lifetime exposure at levels above the MCL: diuresis, increased starchy deposits and hemorrhaging of the spleen.

Methemoglobinemia (also known as "Blue Baby Syndrome") is a health problem associated with nitrate ingestion. Elevated nitrate concentrations in drinking water are linked to health problems such as methemoglobinemia in infants and stomach cancer in adults (Addiscott et al., 1992; Lee et al., 1991; Hall et al., 2001; Wolfe and Patz, 2002). Nitrate is converted to nitrite in the stomach, and then absorbed into the bloodstream. There it interferes with the ability of red blood cells to carry oxygen. Symptoms of "Blue Baby Syndrome" include cyanosis (bluish discoloration of the skin and mouth), shortness of breath and fatigue.

Evidence that other health problems are associated with nitrate ingestion is conflicting. Some studies suggest the possibility of association with stomach cancer, enlarged thyroid gland, hypertension, lymphoma, and birth defects, whereas other studies do not. There is not enough evidence at this time to draw firm conclusions (Filintas, 2005).

1.2. Environmental and effective groundwater management and the EU water framework directive (2000/60/EC).

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 put a burden on water quality and quantity. All polluted waters, whether originating from agriculture, industry or households, return, one way or another, to the environment and may cause damage to it or to human health. Clean water is one of the most important needs of our bodies. It is a sad fact that something as essential to life as clean drinking water can no longer be granted to us. Unsafe water is not just a third world problem. In fact, safe drinking water is even harder to find, specially in industrially developed countries in Europe and also in the U.S. .

Therefore, there are significant sources of diffuse and point pollution of groundwater from land use activities, particularly agricultural practices. The intrusion of these pollutants to groundwater alters the water quality and reduces its value to the consumer (Melloul and Collin, 1994). An increasing demand by European citizens and environmental organizations for cleaner rivers and lakes, groundwater and coastal beaches is evident. This demand is one of the main reasons why the EU Commission has made water protection one of its priorities.

The EU water framework directive (2000/60/EC) aims to get polluted water clean again, and to ensure that clean waters are kept clean (Karyotis, 2002; Filintas, 2005).

Despite the adoption of the Nitrates Directive (91/676/EC) throughout the European Union by Member States in 1991 (European Commission, 1991), the nitrate concentrations of many rivers in Greece have continued to increase over the period 1991-2001. The Nitrates Directive requires Member States to designate as nitrate-vulnerable zones (NVZs) all known areas of land that drain into surface and ground waters, where nitrate concentrations exceed 50 mg/l, where nitrate concentrations are showing a rising trend or, where there is evidence of eutrophication and a significant amount of the nitrates present come from agricultural sources. Although incomplete and lacking of coherence, the water monitoring networks set up by Member States show that more than 20% of EU ground waters are facing excessive nitrates concentrations, with a continuous increasing trend in the most intensive areas of livestock breeding and fertiliser consumption.

At least 30-40% of rivers and lakes show eutrophication symptoms or bring high nitrogen fluxes to coastal waters and seas. (European Commission, 2002).

Prevention of contamination is therefore critical for environmental and effective groundwater management. Spatial variability and data constraints preclude monitoring all groundwater and make remediation activities expensive and often impractical (Filintas, 2005). Vulnerability assessment has been recognized for its ability to delineate areas that are more likely than others to become contaminated as a result of anthropogenic activities at/or near the earth's surface. Once identified, these areas can be targeted by careful land-use planning, intensive monitoring, and by contamination prevention of the underlying groundwater. A significant tool that helps to depict the groundwater pollution and to identify contaminated areas is GIS.

Regarding the structure of GIS, is considered that it is constituted by a database that manages cartographic elements such as topographic and photogrammetric measurements, digitalisations of maps etc and a relational database that manages conventional information of matrix form that emanates from various sources or emanates from remote sensing analyses and field samplings (Hatzopoulos, 2002). Essentially, GIS provides a means of taking many different kinds of information, processing it into compatible data sets, combining it, querying and displaying the results on a map (Filintas, 2005).

The objectives of this paper are to document and evaluate regional trends and occurrences of nitrate in the ground water of agricultural watersheds in Central Greece. Also with the use of GIS and Remote Sensing tools, a hydrological analysis was performed and also the nitrates pollution of an agricultural ecosystem in agriculture-dominated watersheds and the correlated vegetation cover was studied.

2. Materials and Methods.

2.1. Study area-climate and irrigation systems.

The study area of the Nikaia, (Larissa Region) is located 8 km south of Larissa city (Thessaly plain in Central Greece) and is illustrated in figure 1.

Figure 1. Simplified map of Greece showing the study area in Nikaia, (Larissa Region), in Central Greece.

The prefecture Larissa has a total extent of 539,290 ha. The total arable land of the study area (Nikaia) consists of around 15,295.25 ha and water drainage is delivered to the Nembeglrioti stream.

During the last decades the use of efficient cultivars, pesticides, mineral fertilizers, farming machinery and irrigation equipment increased considerably the income of the local farmers. Irrigation is prerequisite to achieve high yields since the dry period is rather long (middle May to forepart of October) and precipitation during the summer season is well bellow the demand of the crops (Figure 2).

Mean annual rainfall in the Nikaia

watershed is 430.1 mm with more than 40% falling in rainy season (September-December), (Figure 2).

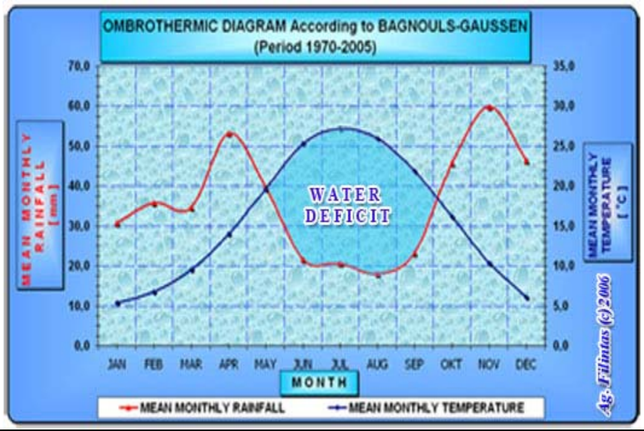

Figure 2. Ombrothermic diagram (according to Bagnouls-Gaussen) of the study area (period 1970-2005).

The mean monthly temperature ranges from about 5.4 ^{o} C in January to 27.2 ^{o} C in July. The study area has a mediterranean climate with warm dry summer and a mild winter, and is designated as **Csa** according to the Koeppen climatic classification (Filintas, 2005).

Three irrigation systems are practiced in the area: a) surface irrigation which cannot be applied in the whole area of Nikaia due to elevation differences of the land (alternation with sloppy and flat anaglyph), b) sprinkler irrigation which covers a greate area extent and c) drip irrigation which covers the rest irrigation demands.

The application of surface and sprinkler irrigation in the low land sections of Nikaia and especially around the Nembeglrioti stream contributes to nitrates movement in the soil volume. The dominant documented problem in the area is land subsidence and this, as documented by measurements, reduces the distance of water movement in the unsaturated zone. This process in combination to increased N mineralization enhances the risk of nitrate pollution to shallow aquifers and groundwater.

2.2. Methods.

An agricultural land and water quality survey was performed and water samples from various wells were collected and analysed in laboratory. Groundwater sampling is conducted 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 28 sites, as follows:

- from boreholes (wells) and
- from phreatic aquifer.

The samples were stored in fridge to avoid mineralization before the laboratory analyses. All samples were analyzed for nitrate (NO_3^-) in laboratory. Also pH of the samples was measured by a pH electronic meter with a sensor probe in the field and in laboratory also. 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 (USEPA 1980), by the use of a laboratory instrument (spektrofotometer) controlled by a microprocessor, with sensors that were operated in wavelength of 500 nm.
Finally, a general research on cultivators' practises was conducted in the study area.

2.3. Data Sources.

In this study, 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, the satellite sensor TM (Thematic Mapper) data (satellite LANDSAT 5 TM) and ETM+ data (satellite LANDSAT 7 ETM+) (NASA, 2004) from 1992 and 1999 correspondingly, have been used together with ASTER sensor (satellite EOS-1 (former TERRA)) (ASTER GDS, 2005) data taken in the year 2004. The features of satellite sensor data that were used are given in Table 1.

TABLE 1. Information about satellite sensor data used in this study.

SN	Satellite Image	Acquisition Date	ROW/ PATH	Number of Bands	Spectral Range [microns]	Spatial Resolution [m]
1.	LANDSAT 5 TM	02-09-1992	183/033	Total 7. 6 1(Thermal IR)	0.45-2.35 10.40-12.50	30 120
2.	LANDSAT 7 ETM+	28-07-1999	183/033	Total 9. 6 2(Thermal IR) 1 Pan	0.45-2.35 10.40-12.50 0.52-0.90	30 60 15
3.	EOS-1 (ASTER)	22-05-2004	Alterna-tive	Total 14. 3 VNIR 6 SWIR 5 TIR	0.52-0.86 1.6-2.43 8.125-11.65	15 30 90

2.4. Image Processing.

Satellite sensor images were rectified using GPS ground truth data, image GCPs data and image to image registration methods and geometrically corrected to the coordinate system using Greek Geodetic System of Reference (Projection Type: Transverse Mercator, Spheroid name: GRS 1980 and datum: EGSA87) with at least 0.5 pixel, RMS accuracy. Also, all images were calibrated and radiometrically and atmospherically corrected (Filintas, 2005).

In this study, the Iterative Self Organizing Data Analysis Technique (ISODATA) unsupervised classification algorithm was used (Tou and Gonzalez, 1974) at first stage. Afterwards, at second stage in order to study the land changes/land cover vegetation with enhanced accuracy, supervised classification of the satellite images was performed along with the use of ground truth GPS data and aerial photos and finally classification maps with land cover vegetation classes were derived.

In the classification process, classes were determined in accordance with Andersen Level 1 (Anderson et al., 1976).

2.5.Geographic Information Systems (GIS).

A geographic information system (GIS) offers the possibility of structured data management and access (Hatzopoulos, 2002). Within GIS, objects are being built by linking spatial data (points, lines or polygons that are defined by geometry and topology) with semantic information. A GIS can be used to answer different queries depending on the data stored in it and allows also their analysis and derivation for further knowledge from the data set (Filintas, 2005).

ArcGIS V9.0 software, complete with the Spatial Analyst software extension, running on an Intel-PC was used (ESRI, 2003) for all GIS work described in the present study. This software allowed the integration and analysis of vector and raster data formats.

2.6. Preparation of geo-database (tables, databases, vector and raster data), Digital Elevation Model and the parameter maps.

All available data were assembled into a single composite digital database (geo-database). A DEM (digital elevation model) for the study area, giving elevation data at 15 m intervals in the easting and northing directions, was acquired from the digitalization of topographic maps. The soil map of the study area was also imported in digital format (.tif) into the ArcGIS program, referenced to area coordinates and on-screen digitized to delineate the different soil units.

The total number of wells and phreatic aquifer sites in the geo-database is 28 and there is one data set measurement of nitrate and pH of groundwater from 2004. The location of the 28 water wells was digitized according to the resulted table of field measurements with GPS, which was derived from the agricultural land and water quality survey that was performed and the accompanying topographic maps of the study area and were linked to an attribute table containing well depth and groundwater table. A GIS point shapefile of well and spatial locations and the corresponding data was developed. Several types of data were used to construct thematic layers. The concentration of nitrate measurement and pH measurement maps were then classified into ranges defined by EU water quality levels and assigned rates ranging from minimum concentration to maximum. Then it was transformed to geo-database digital feature and used in the analysis (Filintas, 2005).

3. Results and discussion.

The soil media is generally variable. Soil mapping showed that nine soil types can be found in the study area however, the tertiary laying down soils predominate and cover a wide extend. The major soil types except the tertiary laying down soils are the alluvian soils (figure 3.a.). Distribution of the wells in the region is also presented in figure 3.a.. Topography and contours in 20 m interval is showed in figure 3.c..

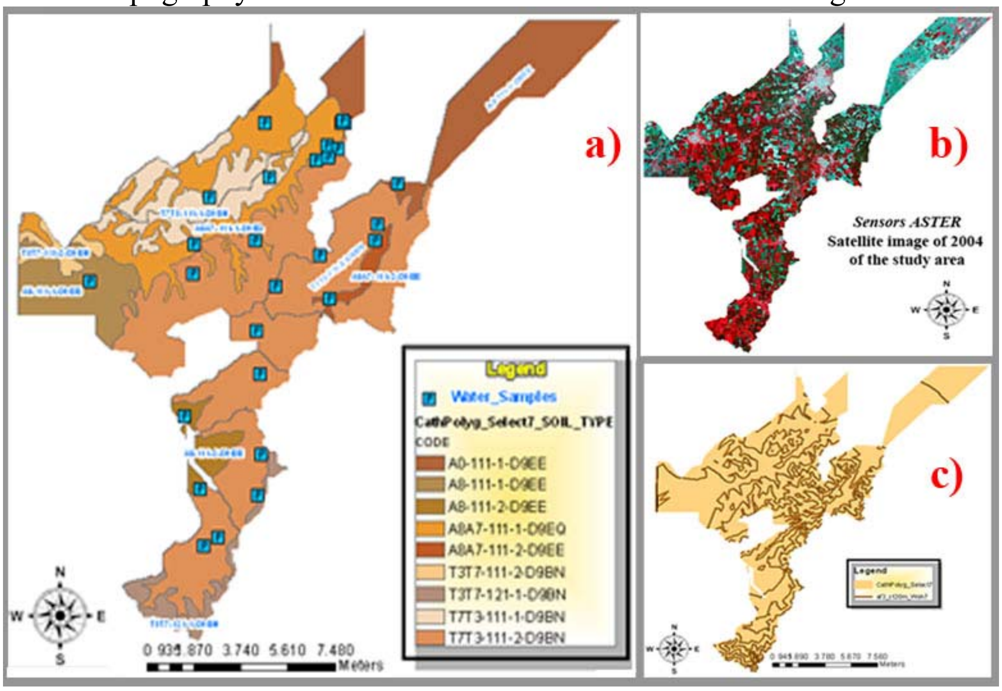

Figure 3. a) Soil map of the study area in Nikaia, (Larissa Region) and distribution of the wells (water samples). b) Sensors ASTER satellite image of 2004 with shape of the study area derived from the original path/row satellite image showing the study area in Central Greece. c) Contours map.

The ISODATA unsupervised classification and the supervised classification of the satellite images (figure 3.b) in order to study the land changes/land cover vegetation with better accuracy, were performed along with the use of ground truth GPS data and aerial photos 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 1992, 1999 and 2004 was satisfactory enough and varied between 81-96%.

The digital elevation layer (figure 4.a.) displayed a height variation above mean sea level between 51.18 m to 345.12 m over the study area. The height increases north to south, west to east and southeast to northwest.

From the hydrological analysis that was conducted, several valuable information and GIS maps were derived (figures 4.b. to 4.f.). In figure 4.b. is depicted the flow direction of surface water in a GIS map and figure 4.c. shows the water stream definition of the study area overlaid to digital elevation model. The drainage lines and the drainage point of the entire area of all the watersheds are showed in figure 4.d., overlaid to DEM. The longest water flow paths and the drainage point of the entire area of all the watersheds is showed in figure 4.e., overlaid to DEM.

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 seven watersheds. In figure 4.f. is depicted the watersheds delineation areas along with drainage lines and the longest water flow paths and the drainage point of the entire area, overlaid to digital elevation model.

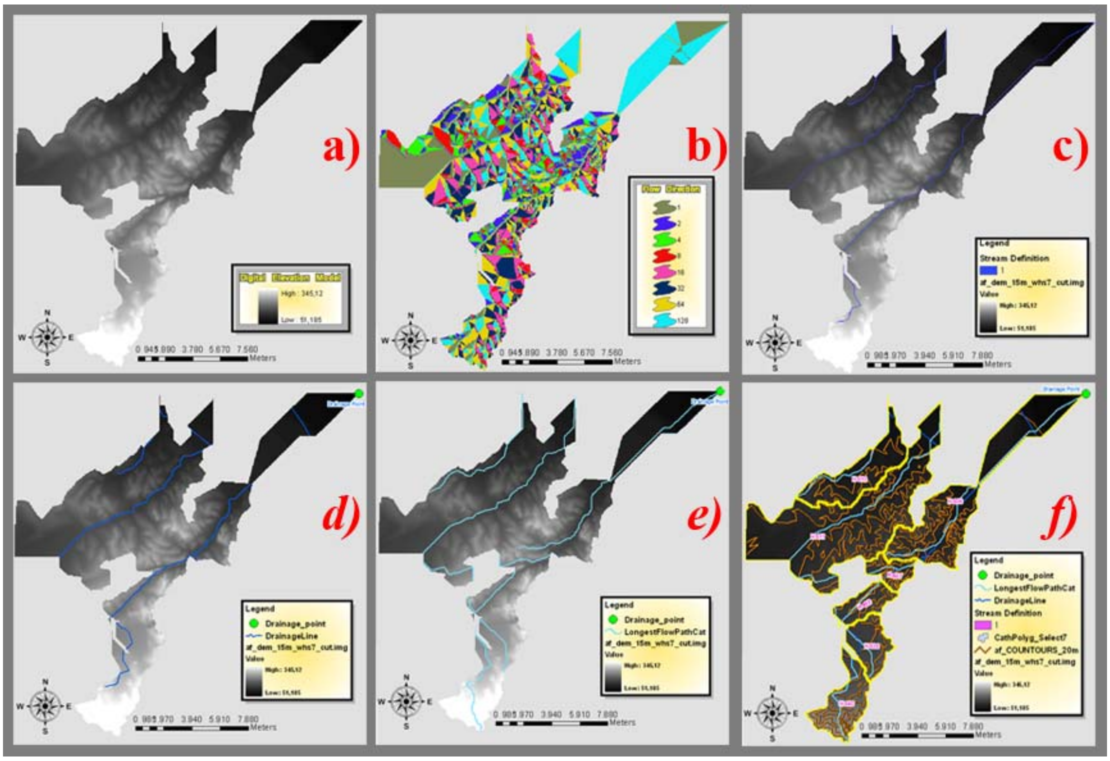

Figure 4. Various maps of the topographic and hydrological analysis of the study area, in Nikaia, (Larissa Region), in Central Greece.

The area (figure 5.a.) and length of the watersheds is presented in table 2.
Water quality depends on factors dealing with soil genesis, climatic factors as well as human activities.

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 Hydro ID	Watershed area [ha]	Watershed length [m]	Shape	Number of Wells
1.	606	3,779.50	56,800.00	Polygon	6
2.	610	1,834.00	33,700.00	Polygon	2
3.	611	6,084.00	65,600.00	Polygon	12
4.	627	554.75	14,000.00	Polygon	1
5.	632	742.00	17,700.00	Polygon	2
6.	638	940.00	17,700.00	Polygon	2
7.	640	1,361.00	26,900.00	Polygon	3
	Total	***15,295.25***	***232,400.00***		***28***

The present study considers water samples from various types of soil. Along with the hydrological analyses, regional distribution of groundwater static levels and that of quality values (nitrates, pH) were recorded for each well and archived digitally. 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) distribution to the groundwater of the study area. The results of groundwater nitrate concentrations GIS mapping for the Nembeglrioti stream watersheds appear in figure 5.b.. The GIS processing of the nitrate concentration GIS map derived 103 isonitrates curves, which are depicting the spatial variability of nitrates pollution for the groundwater of the region (figure 5.c.).

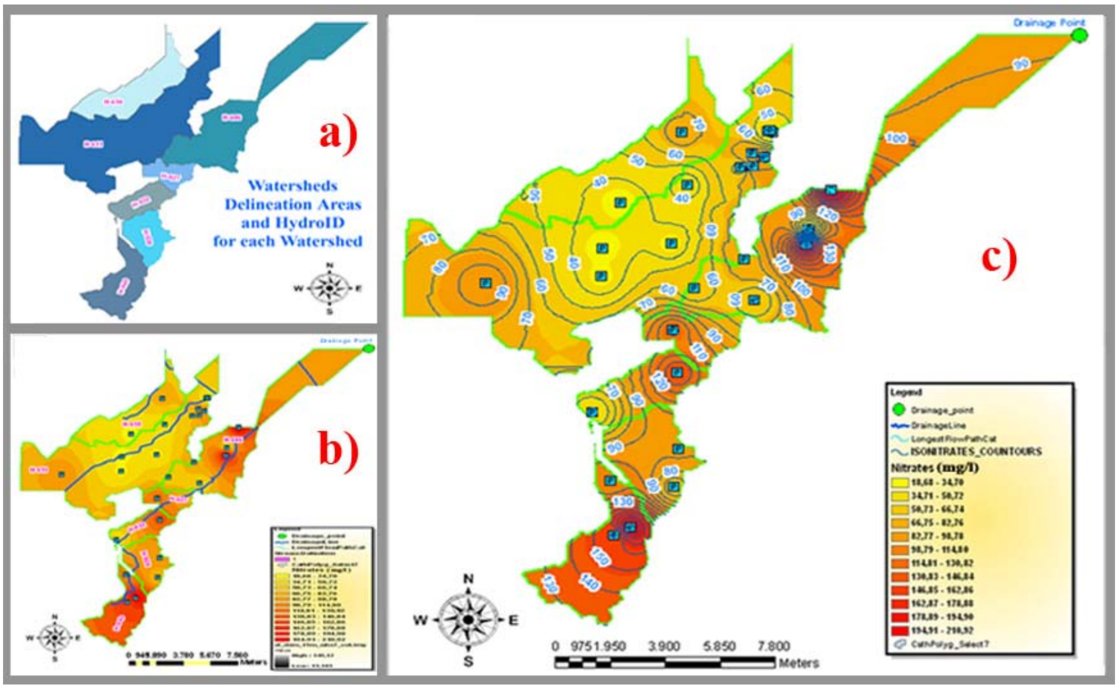

Figure 5. a) Watersheds delineation areas. **b)** GIS map of nitrate-NO_3 (mg/l) distribution to the groundwater of the 7 watersheds delineation areas, containing also the water wells of the region, the watershed HydroID and the drainage lines that were derived from the hydrological analysis. **c)** GIS map of isonitrates curves (mg/l) of the 7 watersheds delineation areas.

The nitrate concentration in water resources it was found that it had a spatial variability which was fluctuated between 18.68 to 210.92 mg/l in the various nitrate classes (figure 6.a.). A classification on the water Nitrate-concentration GIS map was performed and the result was one nitrate delineation zones GIS map of the area (figure 7) with five classes (figure 6.b.).

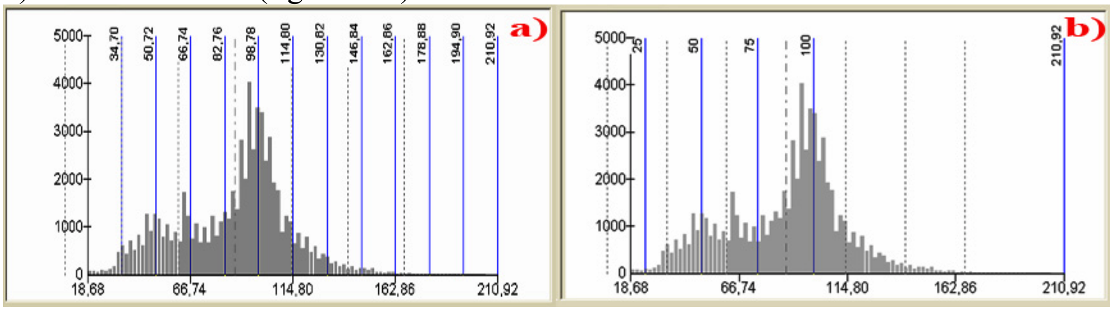

Figure 6. a) Concentration frequency diagram and nitrate classes, of nitrate-NO_3 (mg/l), distribution GIS map. b) Frequency diagram and nitrate classes of nitrate delineation zones GIS map of the area.

As illustrated in figure 7 five main zones of nitrate concentration in water resources of the seven 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 7, originate from an area close to Nikaia. These area exhibit low pollution risk.

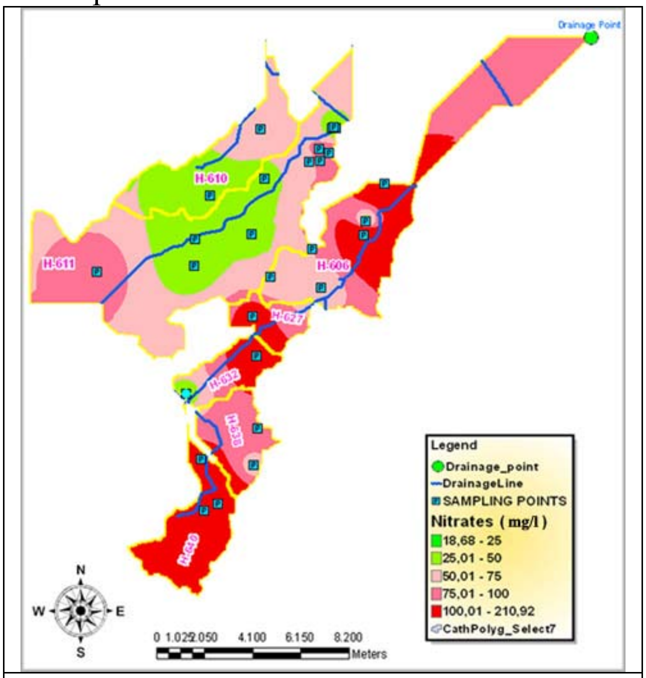

Figure 7. GIS map of the study area showing the zones of nitrate groundwater pollution.

- 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 in figure 7, originate from the areas close to Ampelia, Palaioklissi, Asprogies, Ilistai, Kotroni and Nikaia. 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 Roidies, Tympanon, Chasan Graki, Vrastires, Nees Karies, Ampelia, Kapsantolia, Mpakomagoura, 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 Tympanon, Roidies, Nees Karies, M. Raxi, Palaioklissi and Nikaia.
- The fifth zone has been characterized as zone of excessive pollution risk (red colour) where concentration of nitrates exceeds 100.00 mg/l with maximum 210.92 mg/l and originates from the areas close to Mavrogies, Xara, Koutsouro, Xilades, Malissia, Voidolivado, Kapsantolia, and Nea leyki.

Regional assessment of groundwater quality is complicated by the fact that nitrogen sources are spatially distributed (Tesoriero and Voss, 1997). The identification of areas that receive heavy nitrogen loadings from point and non-point sources is important for land-use planners and environmental regulators. In such areas, management alternatives can be considered to minimize the risk of nitrate leaching to ground water (Lee et al., 1991; Tesoriero and Voss, 1997). Spatial variability in water infiltration rates, various irrigation systems with variable efficiency which results in different distribution of water and nitrates may be among the reasons for the above mentioned variable results of nitrates concentration in groundwater of the study area. Microclimatic differences may cause variation in mineralization and nitrification processes and ultimately nitrate leaching. Inherent soil variability, that exists within most agricultural fields or even within a soil type also gives variable results (Kranz and Kanwar, 1995; Wu et al., 1996).

Additionally, the pH value of groundwater resources it was found that it had a spatial variability which was fluctuated in the various pH classes in between 6.9 to 7.9. The level of water table in the region is getting lower and lower, year by year. This change shows early locational and seasonal differences. Knowing this, the water authority with the farmers can decide not to use these wells until they recovered to their previous levels. Then, they can be allowed to be used again under the control of water monitoring.

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 (Filintas, 2005). 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.

4. Conclusions.

The objectives of this paper were to document and evaluate regional trends and occurrences of nitrate in the groundwater of agricultural watersheds in Central Greece. An agricultural land and water quality survey was performed in 2004, a hydrological analysis was conducted and with the use of GIS and Remote Sensing tools, the nitrates pollution of an agricultural ecosystem in agriculture-dominated watersheds and the correlated vegetation cover was studied. Water for drinking and agricultural use, high in nitrate is potentially harmful to human (particularly for infants and in pregnancy) and animal health. Climate and soil organic matter are amongst the factors that have a profound influence on nitrate N concentration both in soils and water. Terrain morphology, stream network, drainage network, drainage basin point and management in watershed level are of great importance for preventing the spatial dispersion of nitrates to groundwater.

Results showed that in the Northwest part of Nikaia the quality of groundwater is the best. Because of overuse of the groundwater in the centre part, East and Southwest part of the region, the worse quality water of the South now started to feed these wells by changing its flowing and drainage direction. A large part of the study area was classified as excessively and highly vulnerable to nitrates zones and immediate measures for prevention have to be applied. The application of proper amount of N fertilizer according to plant demands in each growth stage and to agricultural fields residual nitrogen may have a substantial effect on nitrate N losses. Taking into account the history of previous crops and their fields soil residual nitrogen, farmers can be assisted in estimating N demands for their crops and particular agricultural fields. Irrigation and drainage conditions in soil depressions may cause salty soils due to high evapotranspiration and deposition of salts in soil surface. Results from the general research on cultivators' practises can be concluded that the applied quantity of nitrogen per hectare in various cultivations was higher than the corresponding crop demands. Because agricultural activities can contribute to excess nitrates, farmers, livestock producers and others involved in providing agricultural services must follow applicable guidelines and regulations to prevent this environmental problem. Otherwise, remedy of degradation in these sites must be done by using biological products. Rotation schemes should be applied in certain districts and legumes are recommended for enhancing soil fertility and aggregates stability. A dense water monitoring network should be the next step ahead for the environmental protection of the region.

Based on the results of the research, the nitrates delineation zones GIS map with the hydrological analysis can be used by scientists, water authority, watershed managers and policy-makers to obtain a more comprehensive view of the current region situation in order to design and implement policy measures and management practices and inform the farmers and the public properly. Moreover this GIS map is a tool that helps to develop guidelines regarding minimizing the nitrates leaching to groundwater and aquifers.

Finally, results showed that nitrate pollution from agricultural sources in agriculture dominated watersheds, is characterised by remarkable spatial variability, depending on the interplay of the effects of human driving forces (land use, agricultural demands and activities) with environmental variables (climate, soil, topography, drainage, etc). These phenomena differ in their scale and spatial features, which is a factor that should be accounted for when designing and implementing policy measures and water and farming management practices.

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