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"The Greek Action Plan for the mitigation of nitrates in water resources of the vulnerable district of Thessaly"

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Abstract

The Plain of Thessaly, central Greece, is characterised by the presence of a large number of different alluvial soils, many of which are highly productive. Irrigated land has increased considerably over the last three decades and this was succeded due to mechanisation, implementation of new productive varieties and the application of fertilisers succeeded this. Intensification of agriculture however, in conjunction with the lack of a rational water resources management scheme, led to pronounced groundwater overexploitation evidenced by head decline that recently has reached alarming levels. In parallel, nitrogen fertiliser's use has increased and caused groundwater quality deterioration and also eutrophication in the River Pinios estuary. An Action Plan aiming to ground and surface water protection from nitrates pollution has been elaborated in order to meet the Greek particularities. Under this Plan a reduction of at least 15-20% nitrogen fertiliser application was suggested. This decrease may be achieved implemented through a set of measures amongst which are the nitrogen's effectiveness increase, the introduction of new irrigation techniques, the cultivation of the suitable crop varieties, as well as by means of financial incentives.

Introduction

Thessaly occupies an area of about 14,000 km^2, or 10.6% of the Greek territory. Out of this percentage, cultivated land covers 36.1%, the rest being distributed to forests, rangeland and other uses.

Nitrates groundwater pollution has raised considerable concern throughout Europe and various attempts have been made in order to address and resolve the problem (Davies, 2000; Scottish Office, 1992). The Greek National Action Plan has been recently introduced and comprises of a set of measures and practices targeting to surface and groundwater bodies protection from agricultural origin nitrates pollution. The latter is in compliance to the nitrates Directive 91/676/EEC (European Commission, 1991). The Action Plan is also inherently correlated to the Code of Good Agricultural Practice (COGAP), which briefly describes the factors leading to nitrogen pollution of agricultural origin. It is a set of rules for proper agricultural practices that are addressing rational management of inorganic fertilisers both in terms of handling (transportation-storage) and also in terms of application to the soil. COGAP aims at assisting farmers in planning for optimised effectiveness of applied irrigation, water-loss minimisation and overall, application of environmentally friendly techniques, whilst on the same time safeguarding their income.

To achieve its aims the plan takes into consideration the current nitrogen fertilisers use regime and shapes general rules against nitrates pollution. Furthermore, it suggests the maximum admissible levels of nitrogen fertilisation for individual main crops, according to the soil class and hydrogeological structure. In addition, it describes the method, the timing and the appropriate fertiliser to be applied, in relation to soil type, as well as to irrigation method and climatic zone's characteristic.

As a prelude to drawing up the Action Plan, all necessary data where collected, archived and analysed in order to achieve deep understanding of the hydrogeological and agricultural environments and also assess the criticality of the current regime in terms of nitrates pollution of agricultural origin.

Materials and methods

Surface and groundwater bodies exhibiting nitrate concentrations in excess of 50mg/l, or indicating a potential to exceed this concentration, were designated as polluted. To identify such areas a dense network consisting of specific groundwater sampling points was designed and frequent quality monitoring was carried out. This program allows for systematic evaluation of qualitative parameters of groundwater resources, hence makes it possible to establish the extent of nitrate pollution from agricultural sources.

Vulnerable areas were initially designated from the results of nitrate concentrations amongst 300 selected sampling points spreaded over the intensively cultivated arable land of Thessaly. In addition to the above, the soil maps of Thessaly were brought into consideration for the main soil properties. The geological maps of the region were also considered in conjunction with knowledge on the hydrogeological structure (Constandinidis, 1978; Kallerigis, 1970; Panagopoulos et al., 1995). Based upon the aforementioned data and the climatic characteristics, an attempt was made to compile the aquifers's vulnerability map, where sensitive areas to nitrate leaching can be easily depicted.

Agricultural land in central Greece exists mainly on alluvial deposits that are characterised by a large variability in soil texture, relief, amount of available nutrients and hydromorphy. In order to make an action plan suitable and workable under the current agricultural practise the soils were grouped into a limited number of so called "soil classes". The grouping was based on soil texture, slope and hydromorphy that were recorded on the soil maps. These soil properties were considered that to a large extent determine the nitrate polluting potential. With regard to soil texture three main groups were recognised: coarse, medium and heavy texture one. Moreover, using a threshold of 6% of mean soil slope, the soils were grouped into lowland and hilly, if they scored a lower or a higher value to the threshold one. With respect to the hydromorphy characteristics, two categories were established: those possessing good to fair hydromorphy and those of insufficient one. This approach resulted in twelve soil classes. To reduce the variability of soil properties into a manageable number of "soil classes", the latter were further reduced by grouping the coarse and medium texture soils with insufficient hydromorphy into one group and by crossing out the hilly areas with insufficient hydromorphy assuming that such cases don't exist. The re-grouping of the identified soil mapping units (Table 1), is based on parameters that mostly affect nitrogen fertilisers behaviour, namely texture, slope and hydromorphy (Karyotis, 1995; Danalatos, 1993). Application of the Action Plan is restricted to classes I,II,III,VI,VII and VIII.

Two main hydrogeological environments were distinguished in the pilot area, namely the karstified limestones and marbles, and the predominantly alluvial sediments. The former are located at the margins of the plains and are characterised by significant groundwater resources (Marinos et al., 1995). Due to their high infiltration capacity and the thin soil cover, the karstic systems are considered to be highly susceptible to pollution. The main aquifer systems are formed within the alluvial sediments that

Table 1. Soil classes grouping

Soil Class	Slope	Texture	Hydromorphy
I	Lowland, <6 %	Coarse	Moderate-well drained
II	Lowland, <6 %	Medium	Moderate-well drained
III	Lowland, <6 %	Heavy	Moderate-well drained
IV	Lowland, <6 %	Heavy	Insufficient drainage
V	Lowland, <6 %	Coarse-medium	Insufficient drainage
VI	Hilly, >6 %	Coarse	Moderate-well drained
VII	Hilly, >6 %	Medium	Moderate-well drained
VIII	Hilly, >6 %	Heavy	Moderate-well drained

fill the basins of the region. Towards the edges of the basin the thickness of the sediments is restricted to 40-60m, whilst towards the central parts and especially at the eastern Thessaly plain, it increases considerably to over 400m (Compagnie General de Geophysique, 1972; Sogreah, 1974). Two main aquifer units are distinguished: a thin, low potential, unconfined and a deeper high potential and occasionally confined aquifer, separated by a clay sequence of variable thickness (Panagopoulos, 1995). Water needs of the region are mainly covered by groundwater abstracted from a large number of boreholes that tap both aquifers.

In order to develop a flexible fertilisation scheme for the main crops, it was essential to compile soil maps easily understandable to both extension services and farmers. The plan was also supported by groundwater vulnerability maps (Civita, 1994; Zaporozec et al., 1994). Three mapping units were distinguished into these maps, taking into account the geological formations characteristics (Table 2). The criteria used were: structural and hydraulic characteristics of the aquifers, groundwater evolution mechanisms, infiltrability and lithology. The geological characteristics were to a large extent confirmed by borehole lithological section and geophysical logs from the existing wells and boreholes. Such data was considered of critical importance and served to the assignment of a vulnerability index which led to a simplified aquifer vulnerability map (Figure 1).

Results and discussion

Intensified agriculture practices in the region of Thessaly is nowadays considered as a potential source of environmental pollution, mainly due to the increased use of fertilisers and pesticides (Karyotis et al., 1999; Kallergis, 1997). The main reasons that led to the recorded increase of N and P fertilisers use especially between mid70's to mid 80's are the expansion of irrigated land and also the fertilisers subsidies. This increase resulted in constant groundwater quality deterioration. Excessive groundwater heads decline in the central parts of the basin resulted in considerable increase of the hydraulic gradients (Marinos, 1997; Panagopoulos, 1996; III Regional Directorate of Land Reclamation, 1995), hence of average groundwater flow velocity and consequently accelerated pollution dispersion, and also dilution of the pollutants in reduced volumes of water.

For each crop the nitrogen mass balance equation was applied, to calculate nitrogen fertiliser demands. The following attributes were taken into account to determine the nitrogen application requirements in relation to nitrogen polluting potential: geology, soil texture, slope, organic matter content and drainage conditions; irrigation doses and effectiveness, nitrates concentration in the irrigation water; plant nitrogen uptake for maximum yield, nitrogen loss and residual nitrogen content; nitrogen mineralisation and a reduction factor that shows the

Table 2. Groundwater pollution vulnerability zones

Characterisation	Geological formation
Zone I: Highly vulnerable to nitrate pollution	Karstified limestones-marbles (in particular their outcrops). Extensive talus cones and scree zones.
Zone II: Moderate vulnerability to nitrate pollution	Tertiary conglomerates and sandstones of the mid-Thessalian hilly zone. Margins of alluvial basins (including coastal zones). Weathered-fractured parts of essentially aquicludes (ophiolites, schists, neogene marls, flysch). Riverside zones (includes recent fluvial-torrential deposits).
Zone III: Low vulnerability to nitrate pollution	Internal zones of the alluvial basins (accepting that only the deep confined aquifer is being exploited, hence of significance). Durable parts (non-weathered, non-fractured) of aquicludes (ophiolites, schists, neogene marls, flysch).

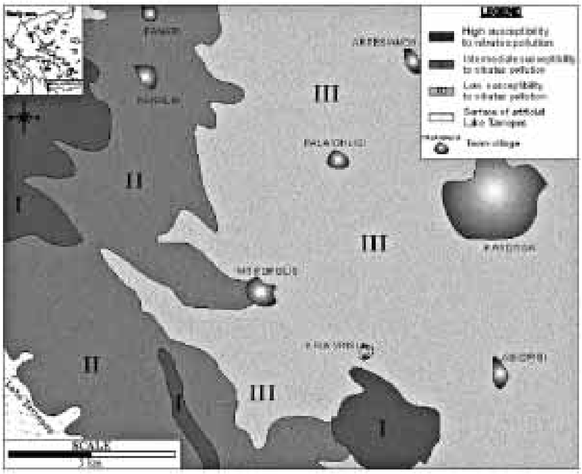

Fig. 1 - Groundwater vulnerability map excrpt

deviation of the maximum yield nitrogen requirement and matches to the fertility potential of each soil class. Tables 3, 4, and 5 list the recommended fertilisation doses concluded from the applied models for cotton, maize and sugar beets, respectively. A mean nitrates concentration in irrigation water of 15mg/l was assumed in the calculations made where no such data were available.

It has to be stressed that the application rates should be adjusted in time to meet the requirements of the individual climatic and soil characteristics targeting a sufficient groundwater protection. This effort can easily succeed a reduction of nitrogen application in the magnitude of 10-15% compared to the present fertilisation policy and practice. Further reduction can be achieved increasing the nitrogen effectiveness through the number of N doses. Drip irrigation increases also the fertiliser effectiveness and contributes to reducing fertilisation requirements (Bucks et al., 1982). Site specific soil analysis before sowing and especially residual nitrogen measurements have been found to account for a substantial reduction in the calculated fertilisation needs under certain soil and climatic conditions.

It is of great importance to monitor systematically the nitrogen levels in groundwater. Towards this prospective, the pilot groundwater sampling network established at 1996, has been made more dense and expanded to cover (Figure 2) the entire arable land, following the methodologies of Bachmat (1984), and Herzog et al., (1991).

Data obtained from the groundwater samples indicate a strong fluctuation of nitrates and ammonium ions that could be attributed to the seasonal variations of redox conditions in the unsaturated-saturated zones system. It however has to be stressed, that in a large extent of the monitored region nitrate concentrations are below of 50mg/l, whilst only few areas exhibit higher levels. Therefore, the specific monitoring system is predominantly orientated to pollution prevention rather to remediation measures.

The results also suggest that leaching and **built-up** of agricultural origin nitrates are related to the land use change, the effective precipitation, irrigation practice and also the time required to achieve a new equilibrium in the groundwater surface.

The Action Plan for Thessaly has been already shaped and is going to dictate the nitrate fertiliser practice for the period of 2001-2006. This target will mainly be achieved through the fertilisers optimisation application methods, which are expected to increase the fertilisers recovery factor. The residual nitrogen available data suggests that a 50 % reduction of the presowing amount can easily be succeeded and accompanied by the split of the remaining nitrogen amount into five doses by fertigation will account for a considerable decrease in nitrogen losses. In addition, the crop cover practice introducing legume crops during the autumn-winter period when the nitrogen can be easily leached, crop rotation and partially set aside are practices expected to reduce the nitrogen losses by a factor of as high as 30-35%.

Farmers are now obliged to apply lower amounts of fertilisers according to the Action Plan recommendations that are formulated to meet not only the needs of the individual crops but also the environmental ones that prevail in the various agrosystems. Amongst them are erosion risk measures at hilly areas, and rational irrigation rates especially in areas suffering severe groundwater head decline.

From the preceding discussion it is concluded that groundwater protection against nitrate pollution can be achieved through numerous measures that are mostly focused on the pollutant decreased inputs to

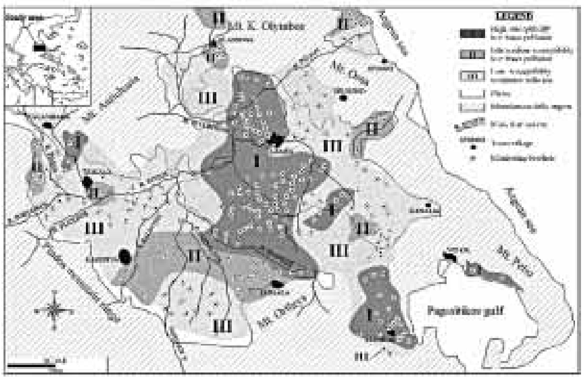

Fig. 2 - Monitoring network in Thessaly and nitrate pollution risk zones distribution

Table 3. Parameters used in the calculations for cotton recommended nitrogen dose

Soil type	Texture	Drainage	Slope	N mineraliz. Kg/ha	Irrigation mm	Applied water per dose (mm)	Recommended Kg N/ha
Lowland	Coarse	Good to moderate	< 6 %	10	400	31	130
Lowland	Medium	Good to moderate	< 6 %	30	350	35	120
Lowland	Heavy	Good to moderate	< 6 %	40	300	38	110
Lowland	Heavy	Insufficient	< 6 %	40	300	38	70
Lowland	Coarse	Insufficient	< 6 %	cultivation is not recommended			
Hilly	Coarse		> 6 %	10	400	31	130
Hilly	Medium		> 6 %	20	350	35	130

Table 4. Parameters used in the calculations for maize recommended nitrogen dose

Soil type	Texture	Drainage	Slope	N mineraliz. Kg/ha	Irrigation mm	Applied water per dose (mm)	Recommended Kg N/ha
Lowland	Heavy	Insufficient	< 6 %	50	400	57	200
Lowland	Medium	Insufficient	< 6 %	30	300	43	250
Hilly	Medium		> 6 %	20	550	42	210
Hilly	Heavy		> 6 %	20	500	38	190
Hilly	Coarse		> 6 %	10	500	33	220

Table 5. Parameters used in the calculations for sugar beets recommended nitrogen dose

Soil type	Texture	Drainage	Slope	N mineraliz. Kg/ha	Irrigation mm	Applied water per dose (mm)	Recommended Kg N/ha
Lowland	Coarse	Good to moderate	<6 %	10	500	33	160
Lowland	Coarse	Insufficient	<6 %	30	300	43	170
Lowland	Medium	Good to moderate	<6 %	30	550	42	150
Lowland	Heavy	Good to moderate	<6 %	40	600	46	200
Lowland	Heavy	Insufficient	<6 %	50	400	57	140
Hilly	Coarse		>6 %	10	500	33	160
Hilly	Medium		>6 %	20	550	42	170
Hilly	Heavy		>6 %	30	500	38	150

the system. However, the artificial recharge can also serve as an alternative measure to alleviate of the pollution problem and also to the restore groundwater potential. Artificial recharge can be performed using the river Pinios winter runoff and its tributaries that cross the region, and also the excess discharge of the numerous karstic springs. Finally, it is believed that the Action Plan will further increase its efficiency should it be accompanied with financial incentives for the farmers.

Conclusions

Irrigation and drinking demands in Thessaly are predominantly covered by groundwater abstraction through a dense network of shallow and deep boreholes. Despite the fact that the aquifers in the pilot area have been classified as low to moderately vulnerable to nitrogen pollution, signs of pollution are evidenced to an areal extent which accounts for about 10% of the total arable land.

Results of the pilot project concerning nitrates pollution in Thessaly, operated within the framework of the National Action Plan, has indicated that farmers have started altering their attitude on crop fertilisation towards a rational and more scientific approach. So far, they have experienced that reduced amounts of nitrogen fertilization does not necessarily correspond to an analogous yield reduction, especially for cotton. Nitrogen uptake is low during the initial growing stages and so nitrate losses can be considerably diminished with a reduced pre-sowing nitrogen fertilisation. Farmers are now convinced that the nitrogen fertilisation efficiency is increased and can be succeeded by splitting the recommended amount to a number of doses.

Several measures and restrictions are dictated in the Action Plan targeting the reduction of groundwater pollution and aquifer restoration, amongst them the reduction of the pollutant input, saving the irrigation water and restoration of the aquifer systems. Discouragement of crop production is also suggested in the regions where pollution risk is extremely high. Adopted measures against nitrates pollution should always be flexible, meet regional and environmental needs, consider farmers' income and ensure social consensus.

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