1. Introduction

Due to its institutional role on regional water management, the Region of Western Macedonia (RWM) has involved in several programs and co-funded projects in order to exploit and / or customize sound scientific tools.

Such a transferable experience refers to:

the implementation of ÔÈÅ ÉÎÄÅØ ÍÅÔÈÏÄ in order to determine groundwater vulnerability and facilitate the overall water management and water protection;

Below is presented how these existing good practices were implemented and benefited RWM.

2. Existing Good Practice: GIS-based Vulnerability Maps

2.1 Methodology

(The chapter refers to a concise description of the essential characteristics of the methodology / implementation and its intrinsic goals (including also reference to the hydrogeologic and / or land use conditions of the PP))

2.1.1 Background

Vulnerability maps inform about the need of groundwater protection and pollution prevention. The maps help to determine which areas may have groundwater vulnerability problems and what types of site-specific data or studies may be needed. Hazard assessment is used to define the potential hazards caused by human activities and can potentially have an impact on groundwater. Risk assessment is defined as a combination of hazard and vulnerability[1]. Overlaying vulnerability maps, with maps showing the location of pollution sources or polluting land use activities, produces the pollution risk maps[2].

In 27- 6Õ) 3ÎÅÒÁÂÉ ÉÔù ÁÐÓ have been developed using the DRASTIC method. The methodology has been implemented in the frame of the INTERREG III B ARCHIMED project WATER-MAP using data from hydrochemical analyses (NO_3) of groundwater samples. The thematic maps and the final maps of the DRASTIC groundwater vulnerability are developed in a Geographical Information System (GIS).

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[1] Uricchio et al. 2004

[2] Voudouris 2008

The project WATER-MAP involved the development and utilization of vulnerability maps for the monitoring and management of groundwater resources in the Archimed area. Project duration was 2 years and was funded under the Community Initiative INTERREG III B ARCHIMED and implemented by 9 partners from 6 countries:

1. Region of Western Macedonia (Greece)
2. Environmental Centre of Kozani (Greece)
3. Aristotle University of Thessaloniki (Greece)
4. Research Institute for the protection of water resources-Perugia (Italy)
5. Liri-Gargliano & Volturno Rivers Basin Authority (Italy)
6. Development Agency of Larnaca (Cyprus)
7. Malta Resources Authority (Malta)
8. Akdeniz University of Antalya (Turkey)
9. Water and Environmental Development Organisation of Palestine (Palestinian Authority)

The project looked at the topic of integrated groundwater resources management aiming to provide scientifically reliable information to the local authorities in order to develop optimal spatial development strategies.

Within the framework of the project, GIS-based groundwater vulnerability maps with the DRASTIC method were generated in order to determine areas where aquifers are in high risk of pollution and a best practice guide to assist spatial development planning processes.

2.1.2 DRASTICMethodology

The DRASTIC methodology was developed in the United States under cooperative agreement between the National Water Well Association (NWWA) and the USA Environmental Protection Agency (EPA) for detailed hydro-geologic of evaluation pollution potential and is a model used to spatially and comparatively display high vulnerability areas in contrast to low vulnerability areas with respect to the potential to pollute groundwater[3]. DRASTIC is an acronym for:

D - Depth to water table

(Depth to Water affects the time available for a contaminant to undergo chemical and biological reactions such as dispersion, oxidation, natural attenuation, sorption etc. A low depth to water parameter will lead to a higher vulnerability rating).

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[3] Dixon, 2005

R - net Recharge

(Net Recharge is the amount of water which enters the aquifer. This value can be calculated on an annual or monthly basis with data available. Although recharge will dilute the contaminant which enters the aquifer, recharge is also the largest pathway for contaminant transport. Therefore, the amount of recharge is positively correlated with the vulnerability rating. Net Recharge can be calculated using climate data by applying a mass balance on the water. Net Recharge = Precipitation – Evaporation – Runoff)

A - Aquifer media

(Aquifer Media is used to produce a rating based on the permeability of each layer of media. High permeability allows more water and therefore more contaminants to enter the aquifer. Therefore a high permeability will yield a high vulnerability rating.)

S - Soil media

(Soil media affects the transport of the contaminant and water from the soil surface to the aquifer. Soil media can affect the types of reactions which can take place. Sorption phenomena, for example, can be affected by the structure of the soil surface. Additionally, different soils will provide better habitats for microorganisms which can potentially biodegrade the contaminant.

T – Topography

(The topography of the land affects groundwater vulnerability because the slope of the land is an important factor in determining whether the contaminant released will become run-off or infiltrate the aquifer. With a low slope, the contaminant is less likely to become run-off and therefore more likely to infiltrate the aquifer. Digital Elevation Data (DEM) may be used to calculate).

I - Impact of the vadose zone

(The vadose zone is the typical soil horizon above and below the water table, which is unsaturated or discontinuously saturated. If the vadose zone is highly permeable then this will lead to a high vulnerability rating).

C - hydraulic Conductivity of the aquifer

(The hydraulic conductivity relates to the fractures, bedding planes and intergranular voids in the aquifer. These components become pathways for fluid movement, and likewise pathways for contaminant movement once a contaminant enters the aquifer. The hydraulic conductivity is positively correlated with the vulnerability rating).

Determination of the DRASTIC index involves multiplying each parameter weight by its site rating and summing the total. The equation for the DRASTIC Index (DI) is:

$$DI = DrDw + RrRw + ArAw + SrSw + TrTw + IrIw + CrCw$$

where: D, R, A, S, T, I, C were defined earlier, r is the rating for the study area and w is the importance weight for the parameter.

For each parameter there are two weights. The first is for the application of DRASTIC to generic municipal and industrial pollutants (typical), whereas the second is for agricultural pesticides (specific). Each parameter has a rating scale between 1 and 10. Higher sum values represent greater potential for groundwater pollution, or greater aquifer vulnerability. The steps for implementing the method DRASTIC include[4]:

- Definition of the study area
- Collecting data relating to the required parameters
- Digitizing source data
- Apply DRASTIC method to assess vulnerability of groundwater to pollutants
- Creation of thematic maps and
- Production of the final map using the international color code.

2.1.3 Hydrogeologic and / or land use conditions of the study areas

GENERAL CHARACTERISTICS: Western Macedonia is located in NWestern part of Greece, covering an area of 9.450 km^2. In a large part of the area irrigated agriculture is practiced. The land is used mainly for cultivation of cereals and cows and sheep graze the area.

The main aquifer systems are developed in Quaternary deposits and carbonate rocks (karst aquifers). The major water use is in irrigation for agriculture; 82% of the total consumption.

ENVIRONMENTAL PRESSURES: Regional environment is subject to numerous pressures, most important of which are the changes of land uses and of groundwater quality and availability. Based on hydrogeological data, the alluvial aquifer systems are showing signs of depletion due to overexploitation and contamination due to the existence of sources pollutants.

Water resources quality deterioration is exhibited as a result of anthropogenic activities. Untreated waste effluent from industrial and livestock units, waste water treatment plant shortage and the lack of proper landfill sites are major pollution sources of surface water bodies that in conjunction with the agricultural activities are responsible for the groundwater quality degradation. Central municipal sewage treatment systems do not exist in small towns.

[4] Polemio and Voudouris 2007

Fertilizers and agricultural chemical compounds are being used intensively to maintain the productivity of the soil.

VULNARABILITY STUDY CASE: Three representative basins of western Macedonia: Sarigkhiol, Florina and Mouriki were the case study areas for the application of the vulnerability method in the Region of Western Macedonia and are described below.

Sarigkiol Bas in

Sarigkiol basin is located in the north-eastern part of Kozani Prefecture, Western Macedonia region, Greece, covering an area of 423 km^2. The land use is mainly cereal cultivations and cow/sheep graze areas, with a large part of the area irrigated. Lignite deposits that exist in the ÂÁÓÉÎ ÐÒÏÄÕÃÅ ÁÌÍÏÓÔ φυÞ ÏÆ ÔÈÅ ÃÏÕÎÔÒÙõÓ ÔÏÔ

The alluvial aquifer of the Sarigkiol basin covers an area of 60 km^2. The depth to groundwater in the alluvial aquifer of Sarigkiol basin ranges from less than 7 to more than 75 m below ground surface but its maximum depth reaches 110 m.

Based on results from soil analyses, the predominant soil types are: Clay, Silty-clay, Sandy-clay, Sandy-loam, Silty, Silty-loam, Loamy. The highest vulnerability values in the Sarigkiol basin are associated with shallow aquifers without great depth of the vadose zone. Low and very low values of vulnerability are located in the southern part of the basin in which the aquifer has great depth of vadose zone with layers of clay and silt and great depth to groundwater level.

Florina Basin

Florina basin is located in the central part of Florina Prefecture, Western Macedonia region, Greece, covering an area about of 319 km^2.

In the area, two aquifer systems are developed, one alluvial aquifer covering an area about 180 km^2 and a second one in neogene deposits covering an area about 149 km^2. The depth to groundwater in the alluvial aquifer of Florina basin ranges from 0 to more than 25 m below ground surface. In the aquifer media, based on results from soil analyses, the predominant soil types are: Clay, Silty-clay, Sandy-clay, Sandy-loam, Silty, Silty-loam, Loamy. The highest vulnerability values in the Florina basin are associated with shallow aquifers without great depth of the vadose zone. Low and very low values of vulnerability are located in the center of the basin in which the aquifer has great depth of vadose zone with layers of clay and silt and great depth to groundwater level.

Mouriki Basin

Mouriki basin is located in the North part of Kozani Prefecture, Western Macedonia region, Greece, covering an area of 133.6 km^2. The lowland area where the Drastic method has been applied, covers an area of 33 km^2, with mean altitude 665 m and is intensively cultivated.

The main aquifer system is developed in Holocene deposits (above Neogene deposits). The depth of aquifer reaches at 160 m below ground surface. Moreover, in Holocene deposits, a sandy-clay formation is superimposed on successive layers of sandconglomerate –gravel. Due to the existence of the sandy –clay formation, the top of main aquifer is assumed as the depth of water table. The aquifer media in Mouriki basin was classified according to the soil sample analysis as mainly loam sandy and sandy loam. The highest vulnerability values in the Mouriki basin are associated with shallow aquifers without great depth of the upper sandy – clay formation. Low values of vulnerability are located in the NW and in the SE part of the basin where the vadose zone consisting of sandy and clay alternations, has great depth.

For the implementation of DRASTIC method in RWM basins, indices were calculated according the <u>available data</u>:

- Depth to groundwater (D) . The depth to groundwater is defined as the distance from the ground surface to the water table (unconfined aquifers). In confined aquifers, depth to water is defined as the depth to the top of the aquifer.
- Net recharge (infiltration) (R) . The variable is calculated from rainfall data and the coefficients of infiltration of geological formations. Other possible recharge sources are irrigations, artificial recharge etc.
- Aquifer material or media (A) . Aquifer media have been identified from the borehole data and 85 lithological profiles. Based on these profiles, the aquifer media was classified as 1) Gravel, 2) Sand and Gravel, 3) Sandstone and conglomerate, 4) Sand, 5) Sand, gravel and clay, 6) Clay, sand and gravel.
- Soil media (S). The variable S (Soil type) was obtained from soil classification maps (from Institute of Geology & Mineral Exploration). The general soil associations for an area were determined from soil survey maps and soil analyses. The density of soil samples was 5 samples / Km^2 and the depth 0-30 cm from the ground surface. Based on results from soil

analyses, the predominant soil types are: Clay, Silty-clay, Sandy-clay, Sandy-loam, Silty, Silty-loam, Loamy.

Topography (T). The variable T (Topography) was obtained from elevation points, using the triangulation method in ARC/INFO system.

Impact of the vadose zone (I) . The evaluation of variable I was based on data from lithological profiles.

Hydraulic conductivity (C) . The variable C was calculated from pumping test data and bibliography data based on the properties of the aquifer materials, as well as from pumping test analyses and groundwater flow models.

2.2 Reason for selecting the methodology

(Reasoning in what way the selected methodology / implementation is superior compared to other procedures)

In general, vulnerability assessments are categorized as[5]:

- Index methods,

Indexing methods are very popular because they are easy to implement, inexpensive to produce, use readily available data and often produce categorical results[6]. Index methods also assess vulnerability spatially over large regions and can therefore show the vulnerability of the water table or uppermost aquifers in a region.

In index-based methods, parameters depicting the physical properties of the system, such as depth to water and lithology, are mapped based on either existing data sets (e.g., well data, geological maps) or field data. Subjective numerical values or ratings are then assigned to each parameter map. The rated maps are combined to produce a relative indication of the vulnerability spatially over an area. In most cases, the vulnerability value is categorized into a set number of categories. With the use of a geographical information system (GIS), digital maps of each parameter are easily rated and combined to produce the final vulnerability map. Index-

[5] Gogu and Dassargues 2000; Focazio et al. 2002; Liggett and Talwar 2009
[6] Focazio et al. 2002

based methods are best suited to produce regional-scale screening tools for use in decision making, and for prioritizing focus areas and level of site assessments[7].

- Statistical methods

Statistical methods of assessing vulnerability involve the calculation of the probability of a particular contaminant exceeding a certain concentration. These methods are typically used in places with diffuse sources of contamination, such as to detect nitrates over agricultural areas. Statistical methods usually start with an analysis and mapping of water quality from known sites. These maps can then be integrated into linear regression models in which the contaminant concentration is related to a series of factors such as geology, well depth, and/or land use. Statistical methods produce spatially distributed probabilities of exceedance, rather than a categorized high, medium, and low ranking[8].

- Process methods

Process-based methods are powerful for assessing groundwater vulnerability using deterministic approaches to estimate time of travel, contaminant concentrations and duration of contamination to quantify areas of high and low vulnerability. These approaches may include analytical solutions (e.g., Dupuit approximations) or numerical computer models (e.g., SAAT, SWAT, MODFLOW, MIKE-SHE)[9].

Existing know -how of RWM focuses on indexing methods and in particular on the DRASTIC method because of below advantages.

(+) The choice of the most appropriate method for groundwater vulnerability mapping to be used in any area depends on the data availability, spatial data distribution, mapping scale, purpose of the map and hydrogeological setting. The better the data availability, the more detailed the map. In areas where data availability is low but the general hydrogeological setup is known, DRASTIC would be a suitable method of choice[10].

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[7] Liggett and Talwar 2009
[8] Liggett and Talwar 2009
[9] Liggett and Talwar 2009
[10] Abdullahi 2009

(+) DRASTIC is a popular model for groundwater vulnerability assessments as it is relatively inexpensive, straightforward, and uses data that are commonly available or estimated, producing an end product that is easily interpreted and incorporated into the decision-making process[11].

(+) Vulnerability maps created in a GIS environment offer storage, manipulation and analysis of data in different formats and at different scales. This technique requires that all parameters are geographically referenced, digitized, and entered into a data base. Once in the data base, it is possible to register all data as data layers with a common coordinate system and manipulate them to produce thematic maps, and the final vulnerability map of a region.

(+) Implementation of DRASTIC in Western Macedonia region is supported by the Geology Department of Aristotle University of Thessaloniki, which is located close to RWM.

(-) The shortcoming of DRASTIC is that it underestimates the vulnerability of fractured aquifers and that its weighting system is not scientifically based.

[11] Margane 2003

2.3 Benefits

(Benefits obtained through the PP by application of the good practices (and maybe also limitations))

Exploiting the above techniques, RWM managed to:

V Exploit available da ta and create Vulnerability Maps for the local basins (Fig. 1, 2 and 3) resulting in a better overview of the water protection needs.

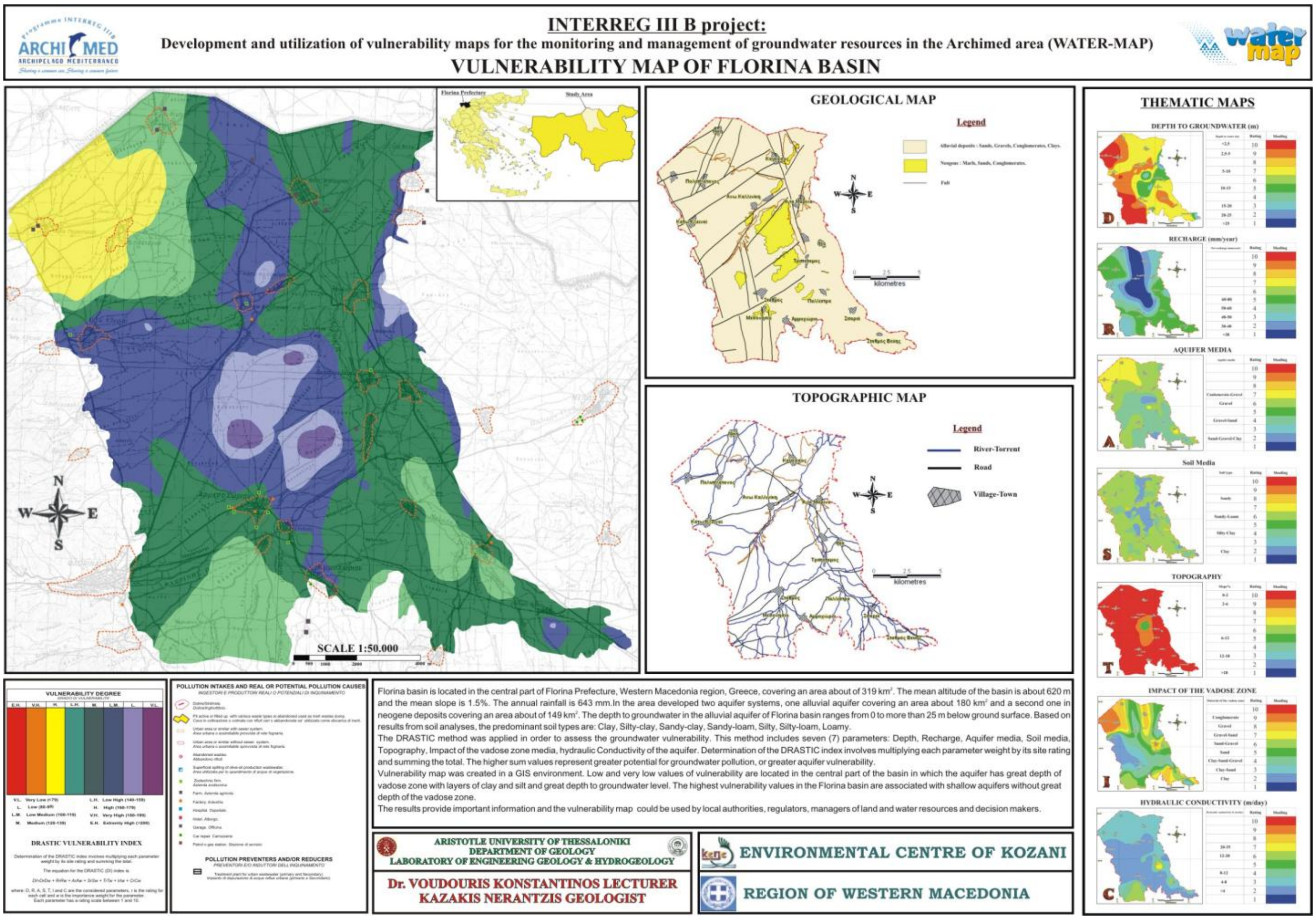

Figure 1: Vulnerability map for Florina Basin

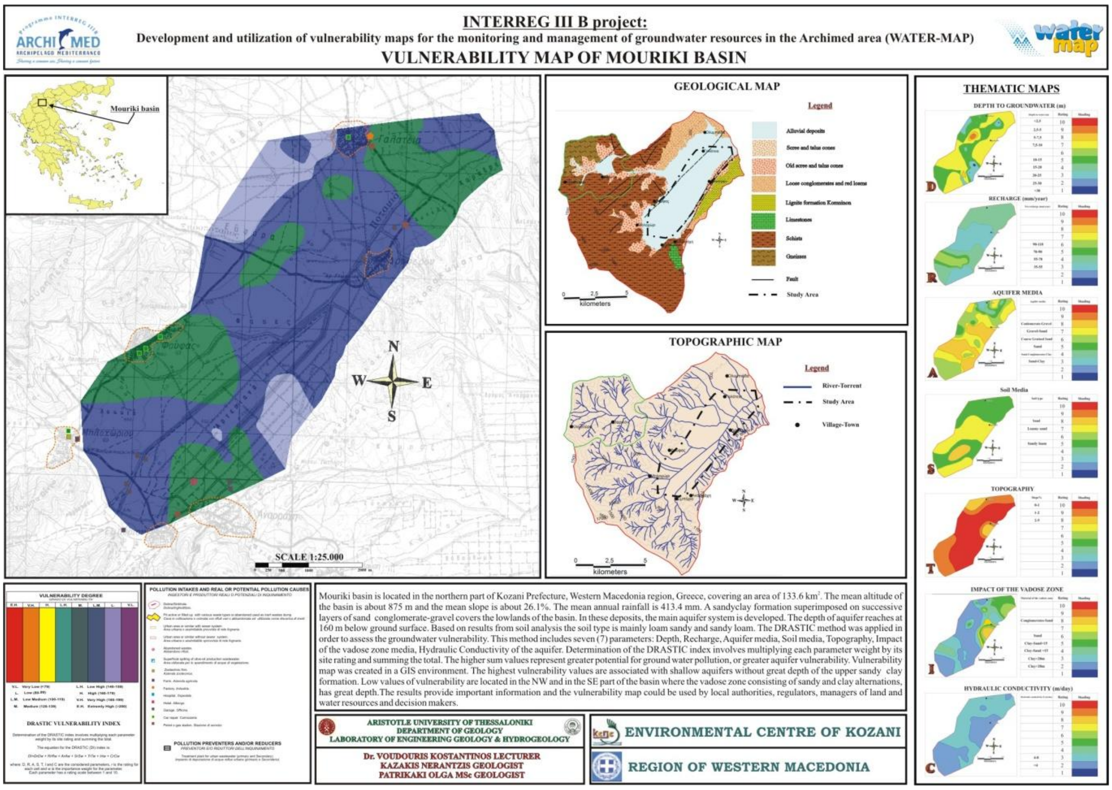

Figure 2: Vulnerability map for Mouriki Basin

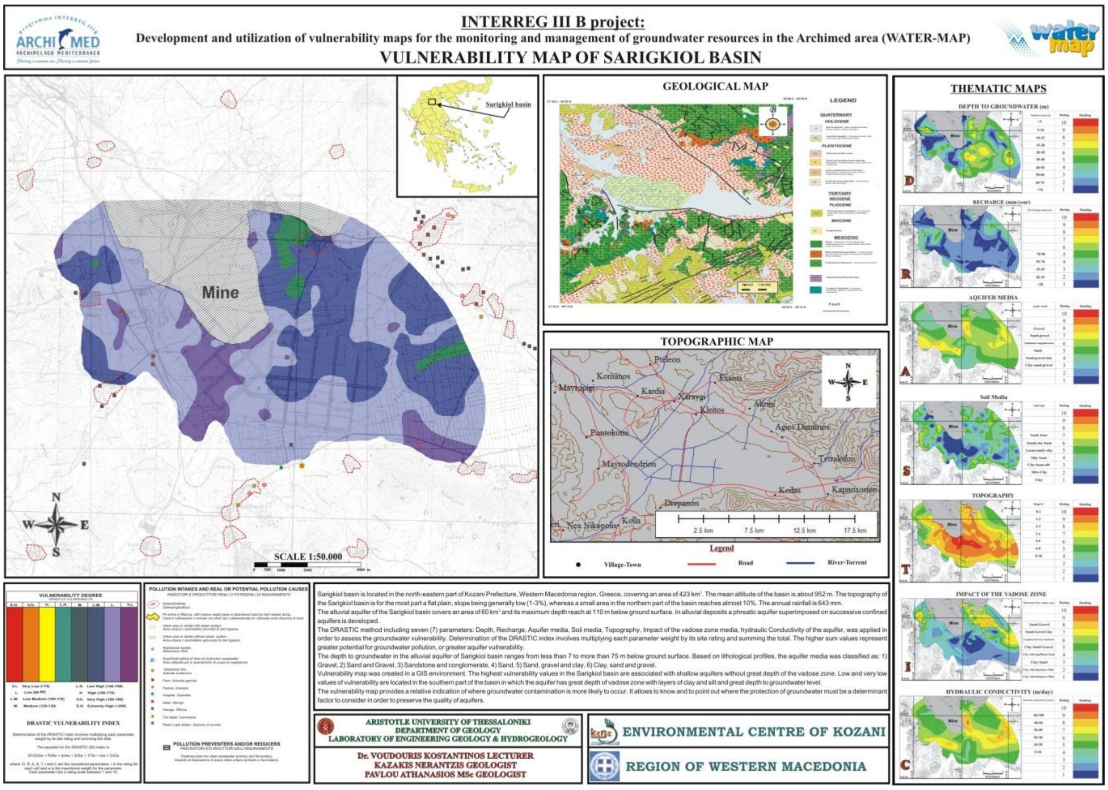

Figure 3: Vulnerability map for Sarigkiol Basin

V Develop a pilot Decision Support System (DSS) with information on land uses, populations etc. The DSS was also delivered within WATER-MAP project and was implemented so as to facilitate and optimize the decision-making process involving the problems of land use, water management and environmental protection. The spatial integration of the vulnerability maps in the decision support system enables the regional authorities to design optimal spatial development policies.

V Determine water vulnerability caused by agricultural activities within the SEE project, called EU-WATER. RWM is currently working on water and nitrogen management in agriculture in order to assess water and nitrogen losses due to percolation and run-off.

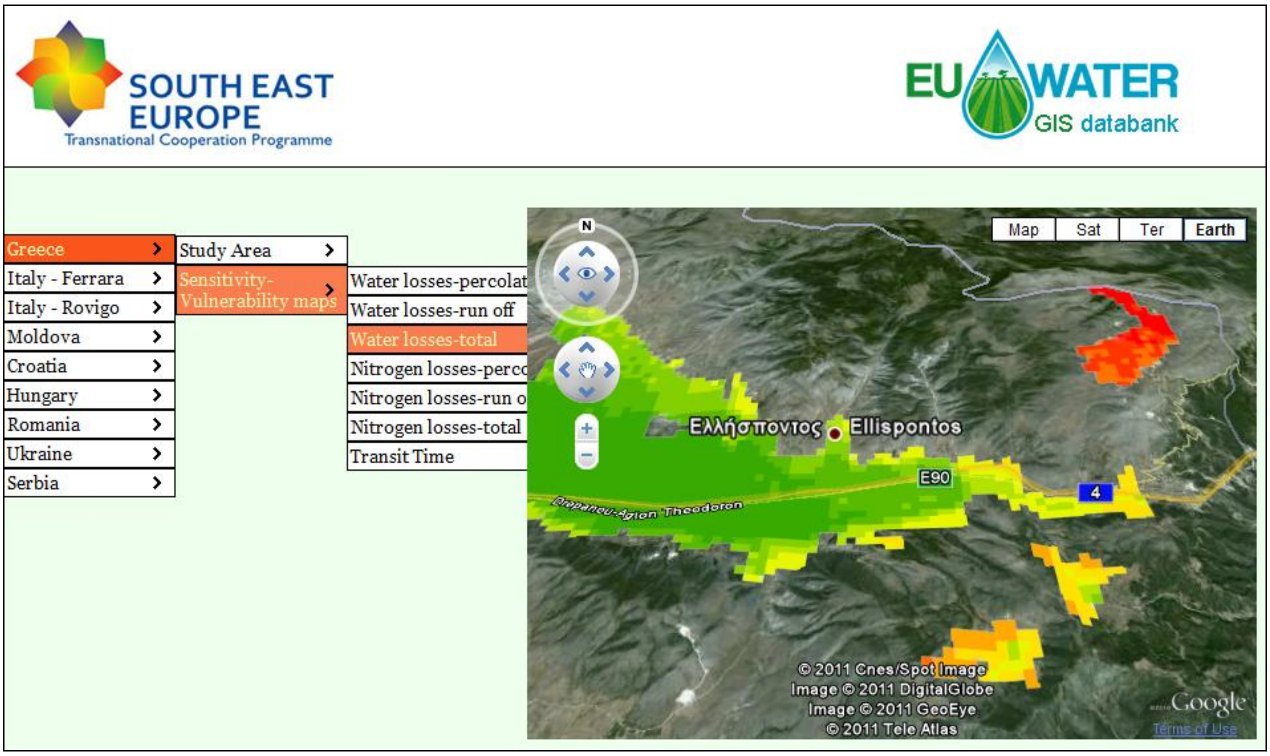

Figure 4: Water vulnerability GIS-map developed for RWM by Aristotle University of Thessaloniki within the EU-WATER project.

2.4 Limitations

Vulnerability maps should be carefully illustrated and their reliability fully tested. The first will be a validation study, which will analyze what relationship exists between map results and groundwater quality data collected within recent years. By analyzing the statistical relationship, it is hoped that a better understanding of the relative importance of each parameter will determine the vulnerability of groundwater against external pollutants.

It is pointed out that, the vulnerability methods must not replace the field studies. The maps could be used as a general guide both for technicians and administrators. The choice of parameter rating should be based on prolonged studies of the hydro-geological conditions. Further investigations are required in order to understand the mechanisms of groundwater recharge and pollutant transport in the aquifer.

2.4 Additional know how

(Did the PP develop additional know how by continuously applying over time the selected methodology / implementation?)

As already mentioned, RWM has capitalized existing know-how of vulnerability assessment in agricultural sector within EU.WATER co-funded project.

The EU.WATERProject (running from April 2009 onwards), which is carried out in 8 rural study areas belonging to 8 SEE Countries, tackles the emergency related to water consumption and contamination in Europe, aims at spreading, at transnational level, an integrated water resource management in agriculture based on the optimization of water consumptions and cutback of groundwater pollution.

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EU.WATER (which starts from the capitalization of the extreme & fragmented load of results of previous projects) moves towards (1) application of the EU Water and Nitrate Directives across SEE Countries (2) development of adaptive-learning practices and innovative solution to contribute at the transition of local agriculture towards innovative and environmental-friendly measures (3) incentives to farmers to adopt eco-prescriptive practices.