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An integrated approach to promote GroundWater sustainability

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Abstract: *GroundWater (GW) plays a key role both in economic and demographic development and it's preservation is a vital factor for sustainable development. GW preservation can be considered as the result of both the protection and the management of the resource. The current status and trends in the EU and around the Black Sea area in respect to groundwater protection and managment, are briefly presented and discussed. Additionally, a "holistic" approach to ensure protection and management of GW resources in a sustainable way is proposed. This approach is based on already proven applied research, conducted during the past years and combines the use of contemporary Geoinformatics Technologies (Remote Sensing, Geographic Information Systems and Information Technologies) with applied geology. Potential outputs, results as well as essential requirements and drawbacks of the proposed integrated approach are also discussed.*

Key Terms: groundwater, environmental protection, remote sensing, hydrogeology, GIS applications.

Introduction: Groundwater (GW) is a natural resource of vital importance to economic and demographic development as it is the main resource of quality potable water. Human interaction with the resource during the last decades has presented characteristics of unconstrained and extensive use of the resource and has led to its degradation both from a quantitative and a qualitative point of view. GW demand and consumption is closely related to land uses which in turn are related to human activities. Municipal, industrial and agricultural use of groundwater to cover the respective needs is a key component of sustainable development both in the EU and around the world. Key factors favoring groundwater use for those activities include: i) its proximity to the point of use; ii) easiness of abstraction/pumping; iii) availability "on demand" for all kinds of needs; iv) availability in areas not covered by surface water (rivers, irrigation channels etc) v) it's high quality as a resource.

An additional pressure is imposed on GW quality by point and non-point potential pollution sources. Point sources can be tracked and controlled but this is a very difficult task regarding non-point pollution sources. Cultivation of large areas imposes an additional serious pressure affecting adversely groundwater quality through the use of chemicals to support agricultural production. Leaching of soil nutrients, pesticide contamination, salinity and sea water intrusion in the proximity of coastal areas are among the impacts on groundwater quality. This problem is becoming extremely important due to the climate change especially in the southern EU countries. Increased demand during the dry seasons is, in many cases, well over the renewable groundwater resources and this situation occurs in large areas of cultivated land. These problems have already been recognized by the EU which has issued various directives (Council Directives 1975; 1991; 1998) the last one being the "Water Framework" directive (EU Council, 2000) http://rod.eionet.europa.eu/instruments?id=5. Despite that fact, problems for groundwater sustainable management still remain and these include the lack of a systematic source protection, legal frameworks which are not always imposed, the lack of reliable information and lack of public awareness.

To achieve a sustainable management leading to the preservation of the resource, policies based on informed decisions have to be implemented. These policies in order to be justified and effective, have to be customized to local hydrogeological conditions taking always into consideration the related agro-economic parameters so, the agricultural community has also to be actively involved. To that end, policies have to be combined with raising public awareness in order to align agricultural production practices with the sustainable management of groundwater.

Informed decisions and public awareness can be based on a GW management system that provides a continuous monitoring of groundwater qualitative and quantitative parameters. Such a system can help manage groundwater resources, fine tune exploitation parameters, indicate pollutants from a very early stage and provide early warnings, evaluate remediation measures effectiveness, project to future consumption and protection needs and over all, help make decisions about the sustainable use of this natural resource. Designing such a system is a demanding task because it actually is a dynamic procedure that changes both spatially and temporarily in parallel with the continuously changing demand, production, consumption and sustainability conditions.

To develop such a system is again a demanding task as the main problem is related to the lack of reliable and accurate data and harmonized methodologies to ensure comparable results and cross-border cooperation. As data availability, accuracy, reliability and costs are among the key issues in all three aforementioned problems, the use of contemporary technologies as Remote Sensing (RS) and Geographic Information Systems (GIS) to overcome these issues is demonstrated. Within this context, methodologies used and results from case studies are presented and discussed.

Basic Concepts: There are some basic principles set by the EU regarding water protection which also apply to groundwater protection: i) High Protection Level: the highest level of protection of human health and of water resources should be pursued; ii) Precaution: Policy should always be based on recognized scientific knowledge, but it should be on the side of safety whenever there are doubts or insufficient information; iii) Prevention: is the key to protect as there is a great difficulty because of great costs related to reversing or rectifying damage to the environment; iv) Polluters must pay: water users or contaminators should pay the full costs of their actions; v) Rectification at the resource: Rectification of pollution at the source applies once environmental damage has been identified. Actions should be taken to rectify the pollution at its source, rather than seeking technical solutions to solve the problem "downstream" of in the case of GW, further across the aquifer system.

From a more “technical” point of view and taking into consideration the aforementioned principles, basic actions towards GW protections focus at three basic aspects: i) Exploration, to verify available resources; ii) Protection, which combines precaution, Prevention and Remediation and iii) Management, including control through legislation and law enforcement, early warnings and regulation of demand and consumption to ensure sustainable management of the resource (Figure 1).

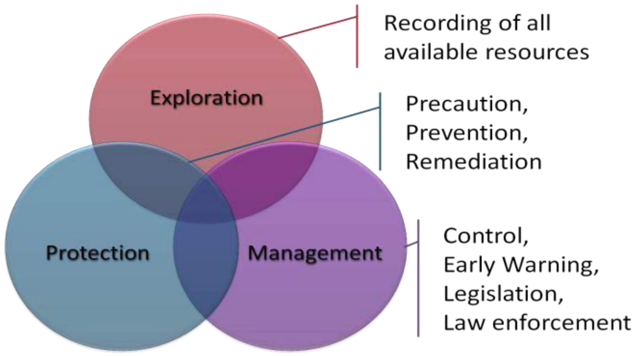

Figure 1. Basic steps towards groundwater protection.

i) Exploration: Groundwater flows through rock formations in high altitudes and infiltrates into basin sediments providing recharge amounts to the exploitable aquifers developed there. The delineation of groundwater flow paths and recharge zones are of great importance as they not only provide information regarding the GW exploitation potential but also about particularly sensitive to pollution recharge areas which should be protected. Data availability is a key issue but data demands can be significantly reduced by combining Remote Sensing methodologies with GIS. Now days, open source and freeware software as Multispec©, GRASS GIS and Quantum GIS provide powerful tools for free and the same stands for satellite multispectral data (Landsat TM, ETM+ and Landsat 8 data) freely available from various sources.

Remote sensing techniques have been used extensively to map geologic formations (Meijerink, 2007), to delineate lithological units (Nabbant et.al., 1995), to map lineaments and detect faults (Wheeler, 1983; Waters et.al. 1990; Gold 1990). Landsat TM4 and various band ratios based on it (4/5, 4/3, 4/7) were found to present geologic changes in a more detectable manner. False Color Composites (FCC) including (as RGB): PC2-4/7-3/1; PC2-4/7-4/3; TM5/7-4/5-3/1; TM4/7-4/3-4, TM4/3-5/7-4/5 were found to provide essential geologic information and lead to delineating fractures in rocks, acting as GW flow paths (Papatheodorou, 2010). These results when combined with GW chemical analyses data (ion concentrations) provide the ability to detect and delineate recharge areas using ion concentration ratios as indices. Ion concentration ratios such as [(Ca+Mg)/(Na+K)] were used as indices of groundwater residence time within the exploitable aquifer and others such as [Mg/Ca] to identify GW flow through specific formations (Figure 2).

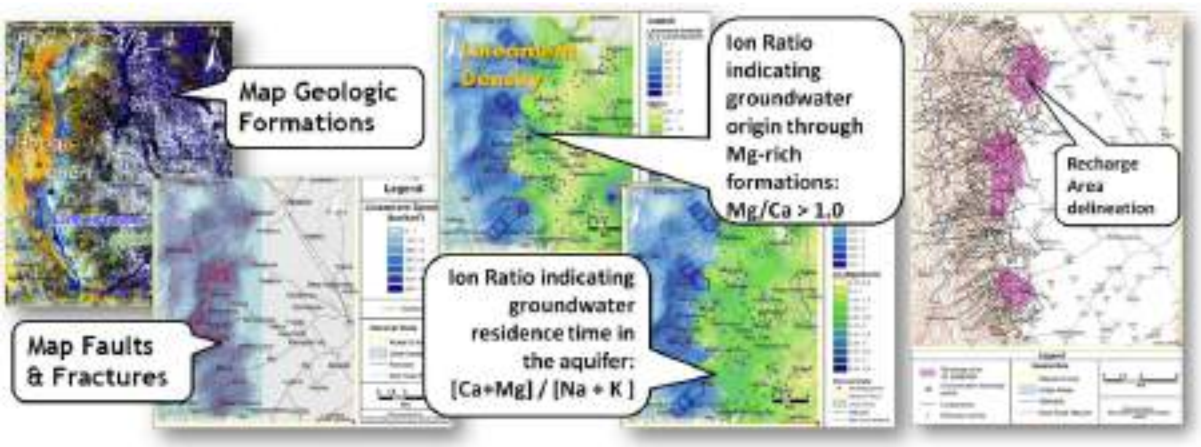

Figure 2. Recharge area delineation by combining Remote Sensing with GIS and hydrochemical data (from Papatheodorou, 2010).

ii) Protection: Groundwater protection must be based on sound scientific basis and cover large areas subjected to pollution risks. Vulnerability maps have proved to be a valuable tool towards this end (Aller et.al. 1987; Rupert 2001; Al-Adamat 2003; Secunda et.al. 2005). Vulnerability maps based on the DRASTIC methodology can be created for large areas as in the case of Emathia and Pieria, Northern Greece (Papatheodorou et.al. 2010, 2012, 2014). These maps can provide reliable information regarding pollution from surface risks and help make decisions regarding land use and development for large areas. The D(epth to groundwater), the R(echarge), the A(quifer media), the S(oil media), the T(opography with the form of slope), the I(impact of the vadose zone) and the hydraulic C(onductivity) of the aquifer are the parameters taken into consideration to assess the drastic Index which is indicative of the groundwater vulnerability from surface pollution (Figure 3).

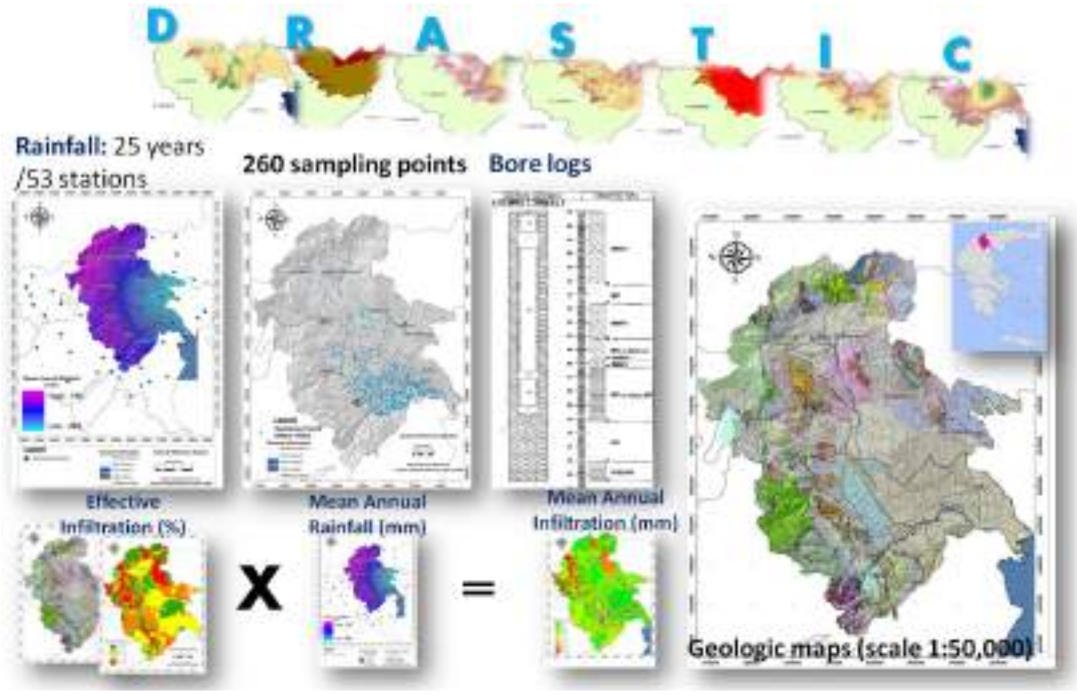

Figure 3. DRASTIC parameters and required information (after Papatheodorou and Veranis, 2012).

The combination of vulnerability maps with land uses and active installations in an area can provide reliable information about the potential pollution risks and provide support to make decisions regarding legislation and planning preventive measures (Figure 4).

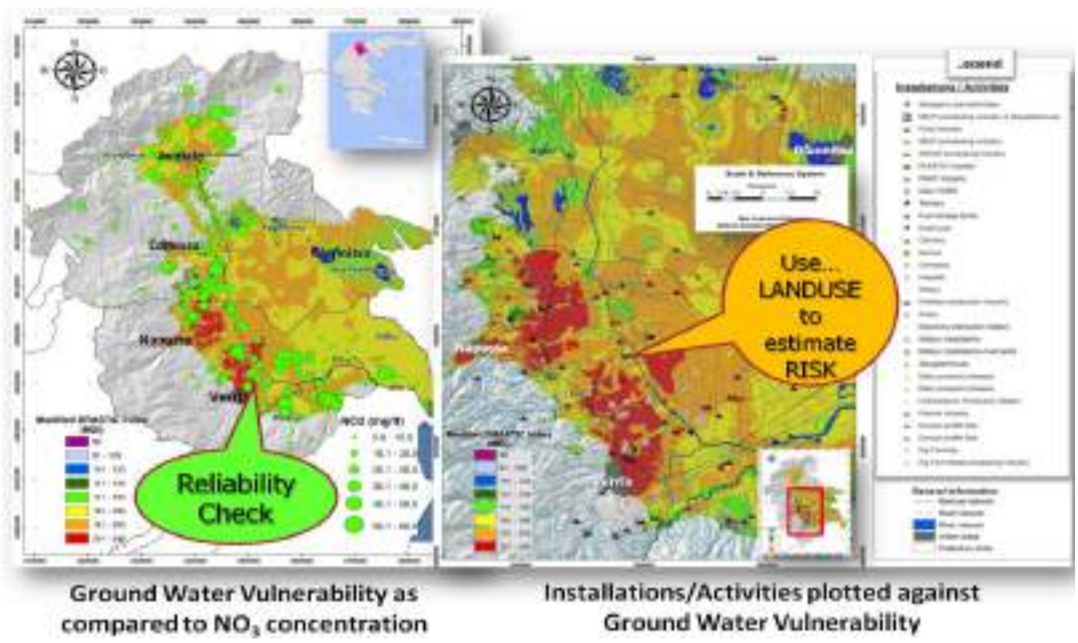

Figure 4. Vulnerability maps combined with Land use to assess the pollution risks and support decisions (after Papatheodorou et.al, 2014).

iii. Management: Information systems have been used extensively to monitor various environmental parameters and provide real time information and various additional outputs including maps, diagrams, tables etc. The design of such a system to monitor GW parameters is a complex process requiring site-specific information regarding the areas of implementation for numerous factors. These are related not only to quantitative and qualitative GW attributes to be measured but to the hydrogeologic and the land use regime of the area as well. Factors that must be known include the scope of the monitoring procedure, the geologic and the hydro geologic regime of the area, the biological and geochemical conditions, potential pollutant transport pathways of (potential) contamination as well as historical data.

The design of such a system needs therefore to be based upon a conceptual model which focuses in understanding the existing problems for the specific site under investigation. The conceptual model must fuse information regarding the hydrogeologic regime, the land uses, the potential contaminants per location according to land uses, vulnerability maps and risks assessed, GW demands, consumption and recharge rates and of course all the parameters related to the dynamic, physical and chemical attributes of groundwater (Papatheodorou et.al. 2008). Various approaches exist regarding the designing of such systems (Environmental Agency UK, 2001; Dutta D. et al 2007) but for any of them to be efficient, the anticipated outputs and results have also to be considered. An indicative case is the GroundWater Information System -GWIS (Papatheodorou & Evangelidis, 2008) which takes into consideration all the aforementioned parameters and includes performance monitoring. Performance monitoring aims at progress verification towards the overall monitoring program goals and is an important asset because it leads to making informed decisions regarding environmental issues as well as possible groundwater monitoring system enhancements (Figure 5).

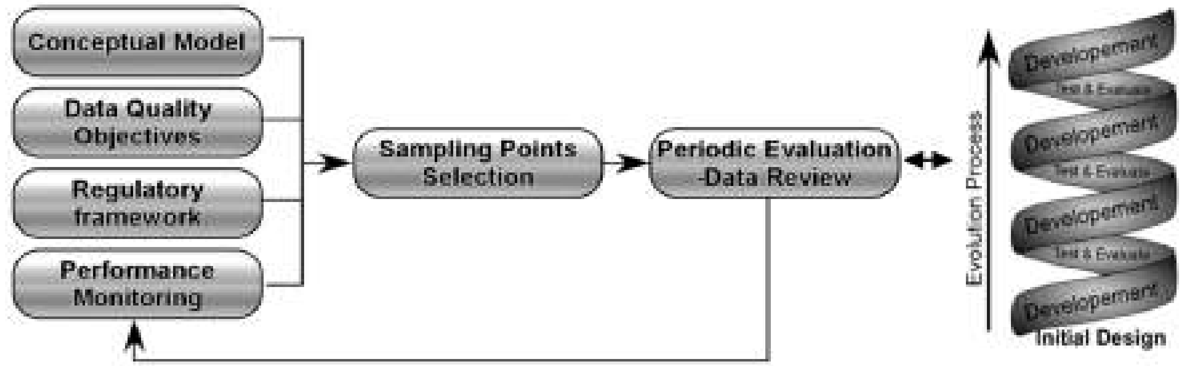

Figure 5: GroundWater Information System's (GWIS) conceptual model.

The GWIS incorporates a multi-tier architecture introduced through three basic tiers (layers):

A. The Data Collection Layer which comprises any kind of field equipment used to perform measurements related to groundwater attributes.

B. The Data / Services / Application Layer which groups the typical data and application (business logic) layers of the 3–tier architecture (Eckerson et al, 1995) along with a layer comprising the required services provided by standard software components (Web Server, Map Server and Database Sever); which includes a number of sub-layers as:
   - Database and Assisting Services.
   - Application and Data access code that contain Web-GIS applications and groundwater simulation models.
   - User access control and content management, that ensures authorized user access built on user profiles.

C. The Presentation layer which aims at providing custom browser based applications to satisfy user interaction.

Sustainability and improvement of the GWIS is through periodic evaluation which includes a review of all the data and results generated and their comparison to historical data. Data reviewing can help detect major changes in the hydro geologic regime of the area which sometimes is indicative of contamination. It can also help reveal contaminant trends and evaluate remedial measure performance in case measures have been taken. The GWIS can be optimized to local conditions for optimal performance with minimal costs. By monitoring various GW related parameters in real time, it can be used as an early warning system when a set threshold in one or more selected parameters is exceeded.

Concluding, the basic characteristics of a groundwater information system as the one briefly described, include its adaptability to user needs which change according to demand and to production and consumption conditions, its conformity with National and EU Provisions and Directives regarding all functional aspects of the system, its ease of use for non-expert users, remote accessibility for data updating and evaluation and the ability to integrate various types of data and information. Moreover such a system can incorporate various models for data processing and interpretation and it can provide results in various forms (tables, charts, maps, reports). Map and data access over the internet provides accessibility to experts according to their access rights and can also be used to inform the public thus helping raise public awareness and promote groundwater protection, conservation and management strategies.

Conclusions and Discussion: Contemporary technologies such as Remote Sensing, Geographic Information Systems and Telecommunications add significant value to scientific knowledge and can help develop solutions in order to manage risks associated with groundwater supply, to support groundwater protection and management in order to ensure sustainable environmental protection and economic growth, to implement measures to showcase and to exchange, test and transfer groundwater management solutions to end-users. These technologies can play an important role in all three steps (exploration, protection and management) towards and effective preservation of the resource.

GroundWater (GW) vulnerability maps when combined with land use data can support decision making regarding land use planning and respective legislation targeting at GW protection. Adaptable to local conditions Information Systems can be used to ensure a sustainable management of the resource, regulated according to demand and available resources. Those systems can also be used as early warning systems, protecting the resource against pollution both from point and non-point pollution sources. Costs to apply a large part of the aforementioned solutions is reduced by using open source and freeware software and freely available remote sensing data making the technologies available for a broader range of potential users thus reducing the time and sharing the effort needed to implement those technologies over large and even cross-border areas.

Risks against such an implementation include a number of lacking GW related information including: i) detailed and reliable data; ii) meta-data, iii) a systematic pollution hazard and risk assessment; iv) harmonized methodologies that produce comparable results especially in cross-border areas; v) not imposed legal framework; vi) public awareness. A response to the aforementioned problems should start with a consensus among members of the scientific community to harmonize methodologies and data, to collect, produce and freely share data with the community and of course, the use of contemporary technologies presented, to better understand the groundwater regime and to develop protection and management systems in order to ensure the sustainable management and the preservation of the resource.

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