Journal of Environmental Protection and Ecology 18, No 1, 168–180 (2017)

Environmental protection and sustainable protection

GEOMATICS FOR ENVIRONMENTAL PROTECTION AND RESOURCE MANAGEMENT

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Abstract. Efficient environmental resource management, attempts to balance between needs and resource availability and it is strongly based on documented decisions. Effectiveness of actions towards a sustainable resource management and protection is built on spatial information availability, reliability and accuracy. Aspects of these parameters including essential requirements, EU provisions, existing problems and potential solutions focusing at groundwater, are presented and discussed. Within this context, the increasingly important role of Geomatics technologies is presented as an example analysis of protection and management of groundwater resources. Technologies applied include remote sensing, desktop and Cloud GI Systems, and Web Services provided by integrated information systems. As it is shown, contemporary Geomatics technologies provide the tools to support efficient groundwater and in principle, any natural resource, protection and management. There are essential requirements which must be met in order to promote sustainable resource management and protection, especially in Cross border areas (CBA). These include the harmonisation of data and of the methodologies adopted, data sharing over web services and competencies/knowledge transfer to establish cooperation and to build competencies.

Keywords: groundwater protection and management, natural resources, remote sensing, cloud GIS, harmonisation, data sharing.

AIMS AND BACKGROUND

Environmental resources are under a continuously growing pressure due to the continuously increasing demand and to climate change. Overexploitation and pollution are among the main hazards leading to their degradation and pose a real threat to environmental sustainability.

One of the most important environmental resources is groundwater (GW) which is a key component of sustainable development both in the EU and around the world reasons including its proximity to the point of use; the easiness of abstraction; its 'on demand' availability for consumption; its availability in areas without surface water; and it is high quality as a source. Unconstrained and extensive use of GW leads to serious aquifer degradation[1], both from a quantitative and a qualitative

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point of view. The increased demands and consumption either for irrigation, industrial and municipal use, affect groundwater quality which is also affected when, during summer in coastal areas, salinity increases due to sea water intrusion as a result of over-exploitation. Serious consequences on GW quality are also due to the use of chemicals in agriculture, which results in leaching of soil nutrients, and pesticide contamination[2]. Consequences caused by these problems are expected to intensify due to the climate change, especially in the southern European countries.

Pressures on GW have not been defined accurately enough so, policies and measures are horizontally applied and in many cases, they prove to be ineffective because they are applied to both areas with and without existing or potential problems and moreover they are unjust when they have a restrictive character, for being applied where there is no reason for doing so. These widely accepted facts have led to a series of measures taken by the European Union and State Authorities, including research funding and legislation, in order to promote the sustainable management of GW.

A serious problem blocking progress of applied scientific research, is the so-called 'information gap' which refers to the lack of 'usable' data[3]. Data are usually not accessible at all or, if found, their evaluation for use is not feasible; even though they have been produced and funded by either National or EU funds, which actually means that they were paid by the public. This fact has already been recognised by the European Union, which has taken a number of actions including legislation which has already come into force and must be taken into account when planning for environmental management. Despite that fact, acquiring data is an expensive process that also takes a lot of time to complete.

This paper focuses on the sustainable management of groundwater resources and tries to briefly present the current status in terms of standing regulations regarding both the resource management and the 'information gap' issue. Within this context an attempt to display the potential Geomatics science and technologies possess in adding value to scientific knowledge and in providing quick and cheap access to valuable information. To document this hypothesis, a number of case studies concluded by the authors, are used.

GROUNDWATER PROTECTION AND MANAGEMENT–CURRENT STATUS IN THE EU

Groundwater is a major resource for drinking water across Europe and also an important factor for various ecosystems so its quality and availability are of vital importance. For that reason, numerous European actions including legislation and funding applied research exist. An indicative list of EU policies and measures planned and/or taken by 2015 includes: the Bathing Water Directive 76/160/EEC (Ref. 4); the sensitive areas under the Urban Wastewater Directive 91/271/EEC

(Ref. 5); the vulnerable zones under the Nitrates Directive 91/676/EEC (Ref. 6); the Plant Protection Products Directive[7] (91/414/EEC) which foresees authorisation to place products on the market if, among others, they have no harmful effect on human health or on groundwater; the Directives 92/43/EEC (Ref. 8) and 79/409/EEC (Ref. 9) including 'NATURA 2000' sites, concerning areas designated for the protection of habitats and species; the Integrated Pollution Prevention and Control (IPPC) Directive[10] (96/61/EC), which applies mainly to industrial activities, establishes provisions for issuing permits for existing and new installations, and aims at protecting soil and water by setting limits for pollutants; the Biocides Directive[11] (98/8/EC) which grants permission to be placed on the market for biocidal products which have no harmful effect on human health or on groundwater and that do not have undesirable effects on the environment, particularly on the contamination of water such as drinking and groundwater; the Landfill Directive[12] (99/31/EC) which aims at preventing or reducing the negative effects of landfill waste on the environment, including groundwater; the EU Water Framework Directive[13] (Directive 2000/60/EC); a report requested to be compiled by Member States between 2004 and 2005, defining groundwater bodies within river basin districts; the 'Groundwater Directive', Directive 2006/118/EC (Ref. 14) which responds and complements the Water Framework Directive (WFD). It calls for GW quality standards by 2008; pollution trend studies carried out using 'existing' data; remediation actions to reverse pollution effects so that environmental objectives are achieved by 2015; measures to prevent or limit pollutant into GW; compliance to 'good chemical status' criteria as set out by the EU standards on pesticides, nitrates and on the respective Member State threshold values.

And more to follow: based on the above, Member States should establish (by the end of 2006) monitoring networks aiming at providing an overview of the chemical and quantitative status of GW; River basin management plans completed by 2009. These aim at investigating the pressures and impact of human activities on GW, economic analyses of water use, protection programmes, monitoring of remediation measures where applicable; the Council Directive 91/414/EEC (Ref. 15) concerning the placing of plant protection products on the market, OJ L230 (Ref. 16), 19.8.1991, repealed by Regulation (EC) No 1107/2009 (Ref. 17) of the European Parliament and of the Council; the Directive 2009/128/EC (Ref. 18) of the European Parliament and of the Council establishing a framework for Community action to achieve the sustainable use of pesticides, OJL309 (2009); and 'a Blueprint to Safeguard Europe Water Resources'[19].

In an effort supervised by the European Environment Agency (EEA) to identify the most important adverse effects of human intervention on the quality and the availability of GW (Ref. 20), a number of factors imposing pressures on groundwater quality and quantity were identified and examined, using a questionnaire distributed to 44 European countries. Indicators used to assess the pressures on GW included nitrates, pesticides, chloride, pH-value, alkalinity, electrical conductivity, GW abstraction and human interventions in the hydrologic cycle.

As was shown in the 'Groundwater quality and quantity in Europe report[21], many of the problems affecting GW quality and quantity are common across Europe so these can only be addressed at a European level. In that case, heterogeneity of data especially in Cross Border Areas (CBA) proved to be a major problem blocking cooperation, competence sharing and overall progress. An additional problem identified was related to monitoring strategies (if any) and methods which were adapted to 'domestic' needs; so various countries had applied different monitoring systems and methods. Different methods applied, led to investigating different aspects and to acquiring different types of data, incompatible between different countries even in respect to the same environmental parameter, making comparison among data from different locations, not feasible.

Another reported issue, related to the data provided, was their low level of reliability since in most cases no additional information (type of the sampling sites, their status, hydro-geological regime, exact location etc) was available[21].

Considering that environmental problems present a strong spatial variability, it appears that in order to properly assess the influencing parameters and pressures on GW, to classify the problems and to make decisions regarding protection and management of the resource, a much more detailed investigation is necessary using harmonised methodologies to ensure consistent implementation especially in CBA. Harmonisation of methodologies can lead to harmonisation of data and there are EU policies in force which set the respective framework.

EU POLICIES ON ENVIRONMENTAL DATA MANAGEMENT

In principle, efficient environmental resource management is strongly based on documented decisions, since it attempts to balance between needs and resource availability. Environmental problems generally present a high spatial variability so, geospatial data needed to investigate environmental issues, come into a variety of types and structures. Effectiveness of actions towards a sustainable resource management & protection is therefore dependent on spatial information availability, reliability and accuracy.

The so-called 'information gap' which refers to the lack of 'usable' data is problem to groundwater related research. It is very difficult to find any kind of data, and even if, as an exception data are found, it is extremely difficult to assess their reliability and accuracy, which are essential conditions in cases where decisions must be based on the respective research outputs. In those cases, data have to be re-acquired and that is a time consuming, very costly procedure which poses a serious, decisive block to research.

As a response to these problems and to promote Environmental Data sharing, the European Union through the European Environmental Agency (EEA), has developed Policies aiming at ensuring: ‘that data is handled in a consistent and transparent manner and; that data providers having agreed to share, are assured that their data are properly handled, disseminated and acknowledged following pre-defined similar rules and principles in all countries and stakeholders’[20].

EEA is supporting the principle that all data and products financed with public means should be fully available to public bodies and to others, with as few restrictions as possible; with a number of legislative steps towards creating a Spatial Data Infrastructure (SDI), in order to facilitate the sharing of environmental spatial information among public sector organisations and to promote the public access to spatial information across Europe in order to develop a better policy-making across boundaries (http://inspire.ec.europa.eu).

A major step towards achieving this goal is the INSPIRE Directive 2007/2/EC (Ref. 22) (Infrastructure for Spatial Information in the European Community), which came into force on 15th May 2007. The INSPIRE Directive is based on the following common principles: (i) ‘Data should be collected only once and kept where it can be maintained most effectively; (ii) it should be possible to combine seamless spatial information from different sources across Europe and share it with many users and applications; (iii) it should be possible for information collected at one level/scale to be shared with all levels/scales; detailed for thorough investigations, general for strategic purposes; (iv) geographic information needed for good governance at all levels, should be readily and transparently available. Easy to find what kind of geographic information is available, how it can be used to meet a particular need, and under which conditions it can be acquired and used.’

The specific policy objectives concern: (i) maintenance of long-term series and continuous availability of data; (ii) further exploitation of data by combined use from different stakeholders, for different applications than their originally foreseen ones; (iii) fully free and open access to all data whilst recognising data ownership and models that enable their creation; (iv) transparency, traceability and integrity of environmental data and analyses; (v) recognition and protection of intellectual rights of the providers; (vi) environmental data management and distribution according to national regulations; (vii) interoperability and use of International standards; (viii) data use and collection over crowd sourcing and citizen science data; (ix) environmental data quality control and quality assurance using the EEA Quality Management System. Crowd Sourced data are excluded in this case; (x) metadata publication, and (xi) sharing EU Data produced within EU funded projects.

For the implementation of aforementioned Directive regarding metadata, the European Commission (EC) has also released the (EC) No 1205/2008 Regulation of the 3rd of December 2008 as well as supportive documents (INSPIRE Metadata

Implementing Rules: Technical Guidelines based on EN ISO 19115 and EN ISO 19119 – 06.11.2013).

Information presented in Metadata files, contains a description of the fundamental characteristics of the respective data file, resources of information or a geospatial service. The file answers to questions as ‘who’, ‘what’, ‘when’, ‘where’, ‘why’ and ‘how’ of the data resource (The Federal Geographic Data Committee – FGDC, http://www.fgdc.gov/metadata). The European Environment Agency (EEA) has also established and supports the operation of Environmental Data Centres which can host data, provided that these follow certain criteria concerning data structures and formats. EEA supported data centres include: the European Environment Information and Observation Network – EIONET[23]); the Shared Environmental Information System – SEIS[24]; the Joint Research Centre[25]; the EUROSTAT[26] and various other remote sensing data resources[27].

EEA also recognises the role of technological progress and innovation in data collection, processing and sharing and encourages users and providers to explore opportunities towards that direction. Obviously, all of the aforementioned rules must be respected by potential research (service) and data providers in EU funded projects.

Pursuant to EU policies regarding data dissemination and sharing, geomatics technologies encompass critical aspects of geospatial data dissemination, including metadata information, geospatial web services, geospatial data sharing and interoperability and thus can provide reliable platforms for data dissemination and sharing over the Web. Since both the legal and the technical frameworks have been defined by the respective EU legislation in force, harmonisation seems to be the only remaining problem to data interoperability. Interoperability of geospatial data from multiple sources can be achieved by defining the domain values to be used for attributes and the association roles of spatial object and data types, as specified by the EU regulation No 1089/2010. Geospatial data have to be served under invocable spatial data services. To this end, Open Geospatial Web Services introduced by the Open Geospatial Consortium provide the requirements that ensure the harmonisation of spatial data services.

As is therefore appears, standing EU policies define the framework for GW sustainable management and Geomatics science and Technologies can provide the means to fully implement.

GEOMATICS IN GROUNDWATER SUSTAINABLE MANAGEMENT

Groundwater sustainability must consider three basic aspects: (i) exploration, to define resource availability; (ii) protection, which is a combination of prevention and remediation activities, and (iii) management, which includes balancing demand to availability by regulating consumption using legislation and law enforcement, in order to ensure sustainable management of the resource.

EXPLORATION

Groundwater aquifers are developed both in coarse sediments (alluvials) and in rock formations. Despite the fact that groundwater is easily detected and abstracted in alluvial formations[28], there is the necessity of defining GW recharge zones, which should be protected in order to prevent surface pollution and dispersion of the pollutants in the rest of the aquifers. Identification of GW recharge sources can be through the use of Remote Sensing and Geographic Information Systems for complementing research with ancillary data[29–31]. Groundwater ion concentrations used as indicators of GW 'residence time' in granular aquifers, can be used to GW to delineate groundwater recharge areas[32] at the margins of plains towards mountainous areas.

The use of ancillary data including the hydrologic network, rainfall data, effective infiltration coefficients, land use and more, in order to define zones of high GW potential, even in theoretically impermeable rock formations, made feasible through Geographic Information Systems (GIS) has also been thoroughly investigated[33–36]. Recent studies suggest that in hard, theoretically impermeable rocks, tracing fractures through Remote Sensing techniques is the key to successful groundwater investigation in such areas[37]. In a case study using Landsat ETM+ images, mapped lineaments potentially corresponding to fractures in rocks, were combined to form a Ground Water Potential Index (GROPIN), with ancillary information as lineament density, effective porosity, rainfall, water surface accumulation in the form of the Topographic Wetness Index (TWI) and Lineament Location. By comparing the mapped fractures to actual boring yields, and through a sensitivity analysis, it was concluded that the successful GW exploration is strongly dependant on the location of the mapped fractures than on any of the rest of parameters used (Fig. 1).

Taking into consideration that tectonic mapping at this detail is not usually available, it is evident that in the case of GW exploration, geomatics technologies can provide feasible and reliable solutions. An additional important act is that the entire investigation was based on free software and data.

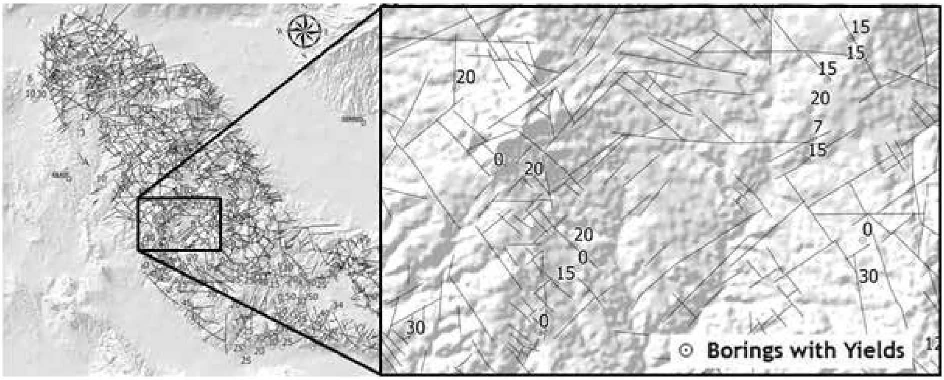

Fig. 1. Location of borings plotted against the lineament map. Successful borings are located in the vicinity of fractures (numbers correspond to yields in m^3/h)

PROTECTION

Groundwater quality can be adversely affected by a series of factors related to human activities and to the respective pollution sources. Fertilisers, pesticides, herbicides, insecticides from agriculture, chemicals and heavy metals from the industry and landfills and sea water are among those factors. Most of these factors are introduced to GW from ground surface, thus GW vulnerability to surface pollution, combined with the location of potentially hazardous installations can provide a measure of the GW Risk to pollution[38] (Fig. 2).

Reliable and accurate GW Risk assessment can support decisions regarding both land use and GW management which can be considered as very effective preventive measures. Reliability and accuracy of risk assessment outputs is closely related to the respective data attributes taking into consideration the scale of implementation which, in this case should be great enough to display the spatial variability of the important influencing parameters; indicatively, 1:25 000–1:100 000 for risk assessment at regional scales and 1:5000–1:25 000 for assessment at local scales. Among the many methodologies proposed[39] to assess GW vulnerability, the DRASTIC methodology[40–43] is considered as one of the most effective since it takes into consideration important hydrogeological parameters, related to GW percolation and flow. These parameters include 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(mpact of the vadose zone) and the hydraulic C(onductivity) of the aquifer. The resulting DRASTIC Index is indicative of the groundwater vulnerability from surface pollution, it provides reliable information regarding susceptibility to pollution from surface risks and it can help make decisions regarding land use and land development for large areas[38].

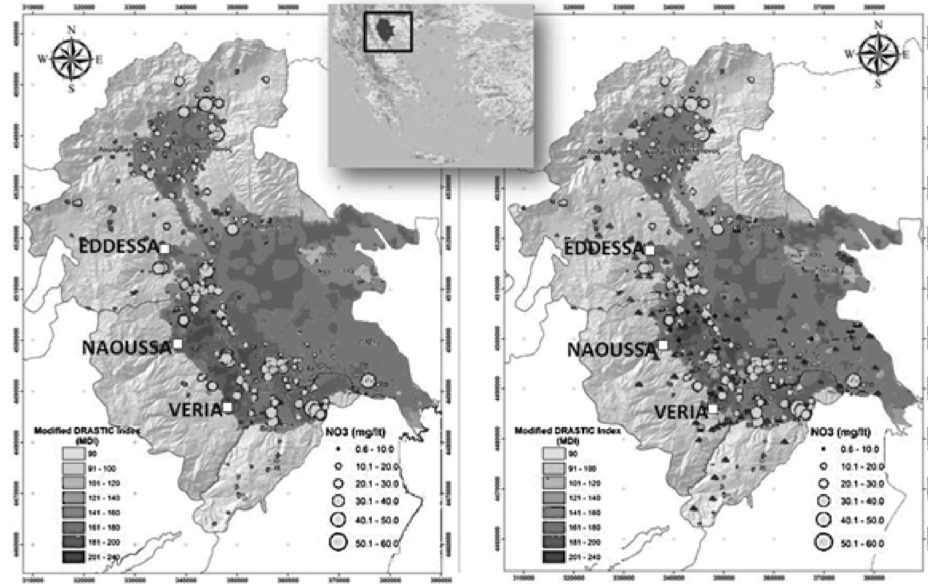

Fig. 2. Ground Water Vulnerability-GWV maps (DRASTIC) of a part of Kentriki Makedonia (Hellas) (left: nitrate (NO_3) concentration plotted against GWV; right: GWV with potentially hazardous to GW installations to help assess the risk to pollution[38])

To successfully implement such an investigation, detailed topography respective to topographic maps at scales greater than 1:25 000 for plains and 1:50 000 for mountainous areas, bore-logs showing the geological structure, soil and rainfall data are necessary. Point and non point pollution source data, including potentially hazardous to the environment installations, agricultural practices and chemicals used are also of great importance to assess the pollution risks. Remote Sensing can provide information regarding the various land uses on a per year basis, at a very low cost. Harmonisation of the process is also important to ensure a consistent implementation and to promote cooperation, sharing of competences and information.

MANAGEMENT

Groundwater management including a continuous monitoring of important GW quantitative and qualitative parameters, can be strongly supported be a GW Information System[44]. The design of a such a system must be based upon a conceptual model which requires understanding the existing conditions and problems for any specific site including the hydro-geologic regime, the land use, 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[44].

Various approaches exist regarding the designing of such systems[45,46]. An indicative case is the Ground Water Information System – GWIS[44], which takes into consideration all the necessary parameters and also includes performance monitoring, which helps calibration and provides the necessary background for proposing monitoring system enhancements to better adapt to changing demands (Fig. 3).

The system has been developed for a part of Thessaly plain (Greece) and includes more than 300 borings acting as sampling points and presents a typical structure represented by a multi-tier architecture including three tiers: data collection which ensures all possible data inputs including data over GRPS/LTE networks; data/services/application including the database and assisting services, WebGIS applications, content management and user access control and; the presentation layer which provides outputs tailored to user demands.

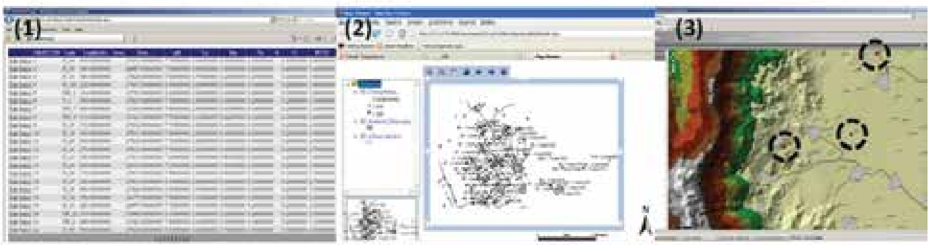

Fig. 3. Ground water information management system: (1) data input; (2) sampling points; (3) alarm (highlighted points in dotted circles) on exceedance of user defined threshold

The proposed GWIS can incorporate various models for data processing and can be used to continuously monitor important groundwater related parameters (quantitative and qualitative) and process them with models tailored to case. The system can also be used as an early warning system when parameters exceed user defined thresholds. As it therefore appears, the GWIS proposed can not only support a sustainable groundwater management but can also act as an effective prevention system and support recovery measures (if necessary) by monitoring the performance remediation measures taken, have.

CONCLUSIONS

EU current policies and standing regulations define at large the necessary steps to be taken towards sustainable groundwater management both from a scientific and a technical aspect. Lack of Harmonization, lack of sufficient data at 'decision making scales' and the lack of spatially registered information have been recognised by the European Environmental Agency.

Harmonisation of methodologies is a key issue and a consensus among scientists activated in this scientific field is necessary. Data harmonisation is feasible by complying to standing EU regulations but acquiring spatial data may still be a problem due to economic costs and time needed.

From the case studies briefly presented, it is evident that Geomatics Science and Technologies can help overcome these problems. Remote Sensing can greatly support groundwater exploration and can help define recharge zones for groundwater protection and land uses (including agricultural practices and crop types); and all by using freeware software and data. Geographic Information Systems can promote data spatial registration, data harmonisation and fusion and can also support mapping groundwater vulnerability and risk at 'decision making' scales. Data at relatively large scales varying from regional (≥ 1:50 000) for mountainous/hilly to local (≥ 1:25 000) for plains should be used. Data should include at least, topography, geology, bore-logs, soil description, rainfall, and potentially hazardous installations and land uses including point and non point potential sources of pollution.

Hydrogeological conditions and groundwater management targets must be used to develop the conceptual model upon which a Ground Water Information Management System should be developed to continuously monitor tailored to case parameters, to manage GW data, to implement models and to provide early warning and management facilities.

Acknowledgements. This research was partially funded by the Special Accounts for Research Funds (Research Committee) of the Technological Educational Institute of Kentriki Makedonia, Hellas.

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Received 5 December 2016
Revised 12 February 2017