Developing tools for managing hydrogeological data in a semi-arid region: the case study of Oulmès (Morocco)

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Abstract

Data and information required by hydrogeological studies are various and complex such as geology, topography, climate, hydrological and hydrogeological raw or pre-processed data. All these data need to be managed, and this can be done in a structured database. A (GIS-managed) hydrogeological database has been developed previously by the Hydrogeology Group of the University of Liège (Gogu *et al.*, 2001) in order to capture, store, edit, query, update and display geographically referenced hydrogeological data. The development of this geo-relational database was constrained by a maximum storage of data with a minimum data redundancy, reduction of storage memory capacity and optimum 'retrievability' of information for further analysis.
In recent years, the use of Geographical Information System (GIS) has grown rapidly in groundwater management and research. GIS is now widely used to create digital geographic databases, to manipulate and prepare data as input for various model parameters, and to display model output. Coupling GIS with this hydrogeological database provides a powerful tool. This GIS-managed hydrogeological database has been also developed for vulnerability-assessment techniques and numerical modelling for groundwater flow and contaminant transport studies. As well as linking between database and GIS, the design of coupling database with process-based numerical models was also performed.
This methodology has been applied, in a semi-arid region: the "Oulmès plateau" located in the Mid-Atlas (Morocco). This study has led to a detailed hydrogeological map at the scale of 1/25000. First, data were collected from existing databases, studies and maps as well as through new field measurements. These data came from numerous and various sources and in different formats (paper or digital diagrams, images, spreadsheets…). After validation, it has been encoded in the hydrogeological database. Because data are geo-referenced, it can be easily represented on the map within GIS-software. The hydrogeological map displays several layers of information as topography, hydrogeological units, hydrographic network, wells, piezometers, isoline of piezometric heads.

Keywords: Groundwater management; Database; GIS; Hydrogeological map; Oulmès; Morocco

Introduction

In hydrogeology as in environmental research, data are numerous, varied and complex. To complete studies successfully, data need to be managed. Thus, a structured database is required and coupling with a Geographical Information System (GIS) provides a powerful tool. A hydrogeological database, developed by the Hydrogeology Group of the University of

Liège (Belgium), has been used in the study on the plateau of Oulmès (Morocco). The aim of this global project was a characterisation of the semi-arid region of Oulmès. Then a lot of data was generated and collected. Subsequently, a hydrogeological map has been carried out.

Development of tools

Database

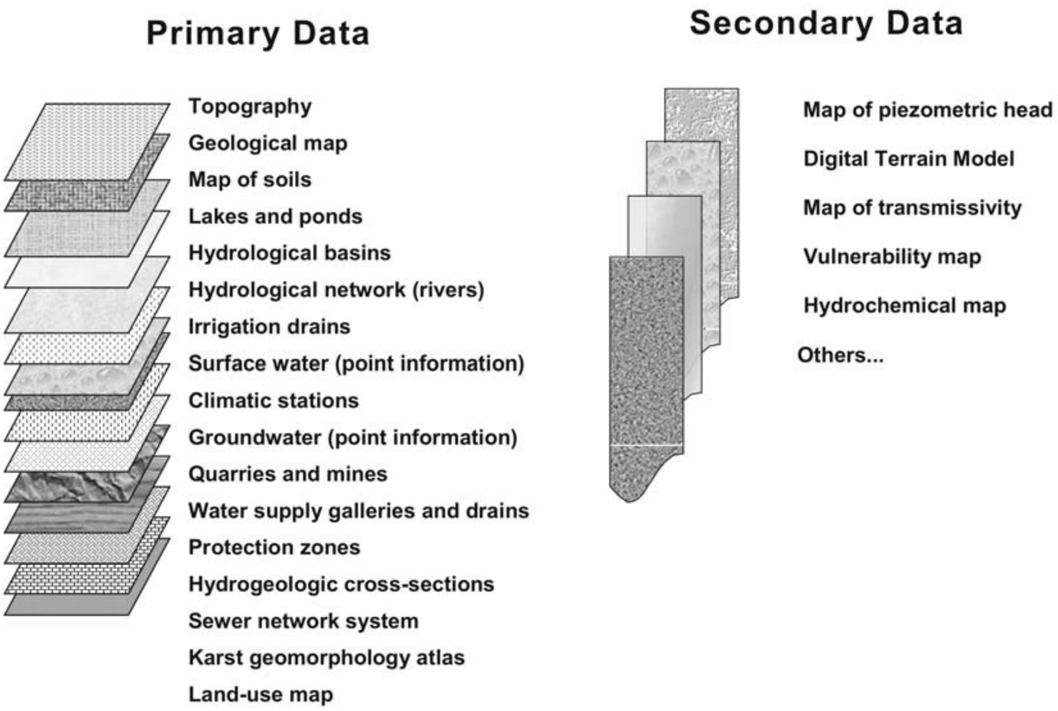
Data and information required by hydrogeological studies are various and complex. Information concerning geology, hydrology, geomorphology, soil, climate, land use, topography, and man-made (anthropogenic) features need to be analysed and combined. Data are collected from existing databases and maps as well as through new field measurements. Use of point automatic collecting systems for some of the physical and chemical parameters is more and more used. Remote-sensing techniques to assess parameters related to soil, unsaturated zone, geomorphology, and climate are increasingly being used. Some of the techniques for measurement of hydrogeological parameters (sampling, monitoring of hydraulic heads and flow rates, geophysical techniques) show a steady improvement with more and more semi-automatic monitoring tools. All the obtained data need to be managed, and this can be done in databases and particularly in GIS linked databases.

Storing data implies now more conceptual choices than previously: it requires data analysis, conceptual design of data models, and data representation. In hydrogeology, because of a limited number of sample locations, point-attribute data also need to be processed by applying adequate interpolation schemas or modelling algorithms. The derived data also need to be managed.

The data-collection operation showed that hydrological and hydrogeological data come from very different sources: water regulators, water companies, environmental agencies, geological services, research offices, and many others. These various sources have strong dissimilarities in type, in quality and in quantity, as well as in storage media. All the data were analysed for import to a single system. Data that appear to be redundant had to be specified in the database schema to avoid any loss of information. Such decisions were based on (1) pumping schedules, (2) data registration formats, (3) uncertainty of existing data (measures and registration), and (4) insufficiency in data registration system. Because pre-processingt of data takes hours encoding or writing import/export codes, data formats are also a very important issue,. Data coming from paper sources, such as tables, maps, and singular data, as well as different spreadsheets and data existing in databases having distinct schemes, were analysed in order to create a unified database system.

A georelational hydrogeological database was created by the Hydrogeology Group of the University of Liège (Gogu *et al.*, 2001). This georelational database has been developed using Access (Microsoft) in order to ensure compatibility in future data-exchange operations. It could also be used to process and analyse spatially distributed data and to provide data sets in order to generate secondary information layers or transmissivity maps, hydrochemistry maps, to properly support aquifer vulnerability assessments, to easily provide values for numerical models parameters and variables, and to create hydrogeological maps (Fig. 1).

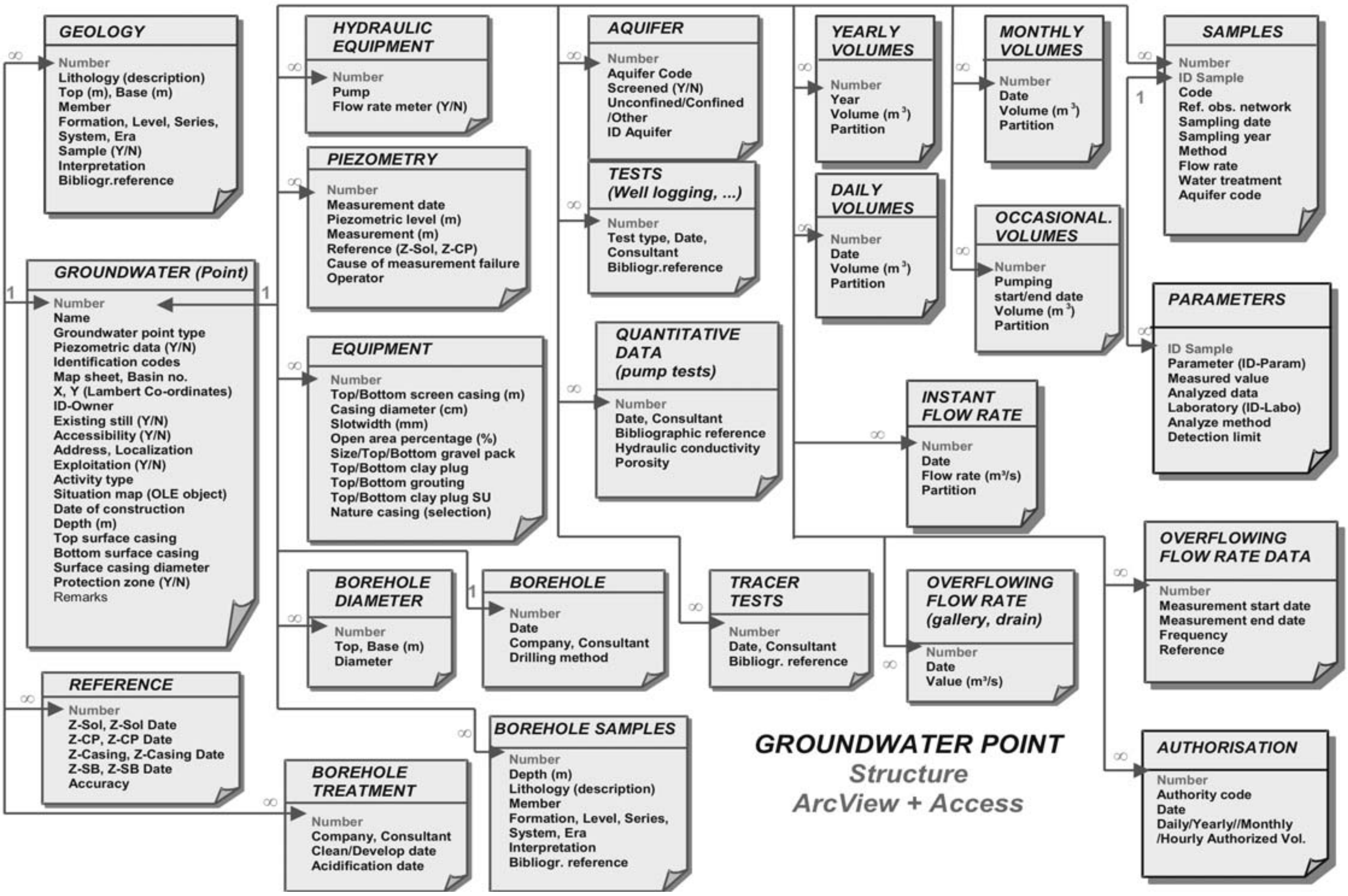
Figure 1: Organised schema of the different needed hydrogeological data



Existing and required data types were examined in order to design the database scheme. Parameters and information were reclassified and regrouped several times. Many hydrogeological parameters and relationships were analysed in order to be placed in the database.

Data are stored in the many tables of the created database. Each table concerns only either punctual (wells, spring…), linear (galleries…) or polygonal elements (protection zones, watersheds…). The main table, called *Groundwater (point)*, contains general information (unique number, geographic position, type, name, code, owner…) about wells, spring, boreholes… (all punctual elements). The others tables contain more specific information as technical characteristics, quantitative data (flows, volumes, piezometric heads, tests…) qualitative data (hydrochemistry), geological data, etc (Fig. 2). The relationships (one-to-one or one-to-many) between those tables are made in using a unique number. Furthermore, to ease data encoding, storage and queries construction, dictionaries were added as reference tables replacing descriptions by ID-numbers (chemical parameters, topographic maps, consultant offices, laboratories…). To improve the use of the database, several pre-defined queries are included in the project, like geocentric query, query based on the owner, on the topographic map, on the investigated aquifer, etc. A user-friendly interface (forms) is created to help the encoding and the reading operations in the database.

Figure 2: Simplified version of the attribute data scheme for "Groundwater Point"



GIS

A Geographical Information System (GIS) is defined as a system for input, storage, manipulation, and output of geographically referenced data (Goodchild, 1996). GIS provides means of representing the real world through integrated layers of constituent spatial information (Corwin, 1996). Geographic information can be represented in GIS as objects or fields. The object approach represents the real world through simple objects such as point, lines, and areas. The objects, representing entities, are characterised by geometry, topology, and non-spatial attribute values (Heuvelink, 1998).

Coupling a GIS and the hydrogeological database provides a powerful tool for groundwater management. One of the applications of this linkage is the development of the hydrogeological maps. Powerful spatial analysis is feasible once the database is established. Maps representing database attribute queries (time- and space-dependent parameter values) can be created. Simple statistics related to hydrogeological entities can be displayed on the screen or printed on paper support maps. Geostatistical procedures (i.e. kriging) complete the analysis. Some of the tools needed to achieve the objectives are already implemented in the base software package, but most of them require knowledge of GIS techniques, database philosophy, and targeted programming using specific programming languages

This georeferenced database is linked to an ArcView GIS project, by spatial queries and a Standard Query Language (SQL) connection (existing GIS function). The connection allows an automatic update of the GIS project for punctual elements (wells, piezometers, springs, climatic stations, river-gauging stations…) every time a new record is added to the database (with its geographic coordinates).Therefore, maps are realized with a GIS software (ArcView-

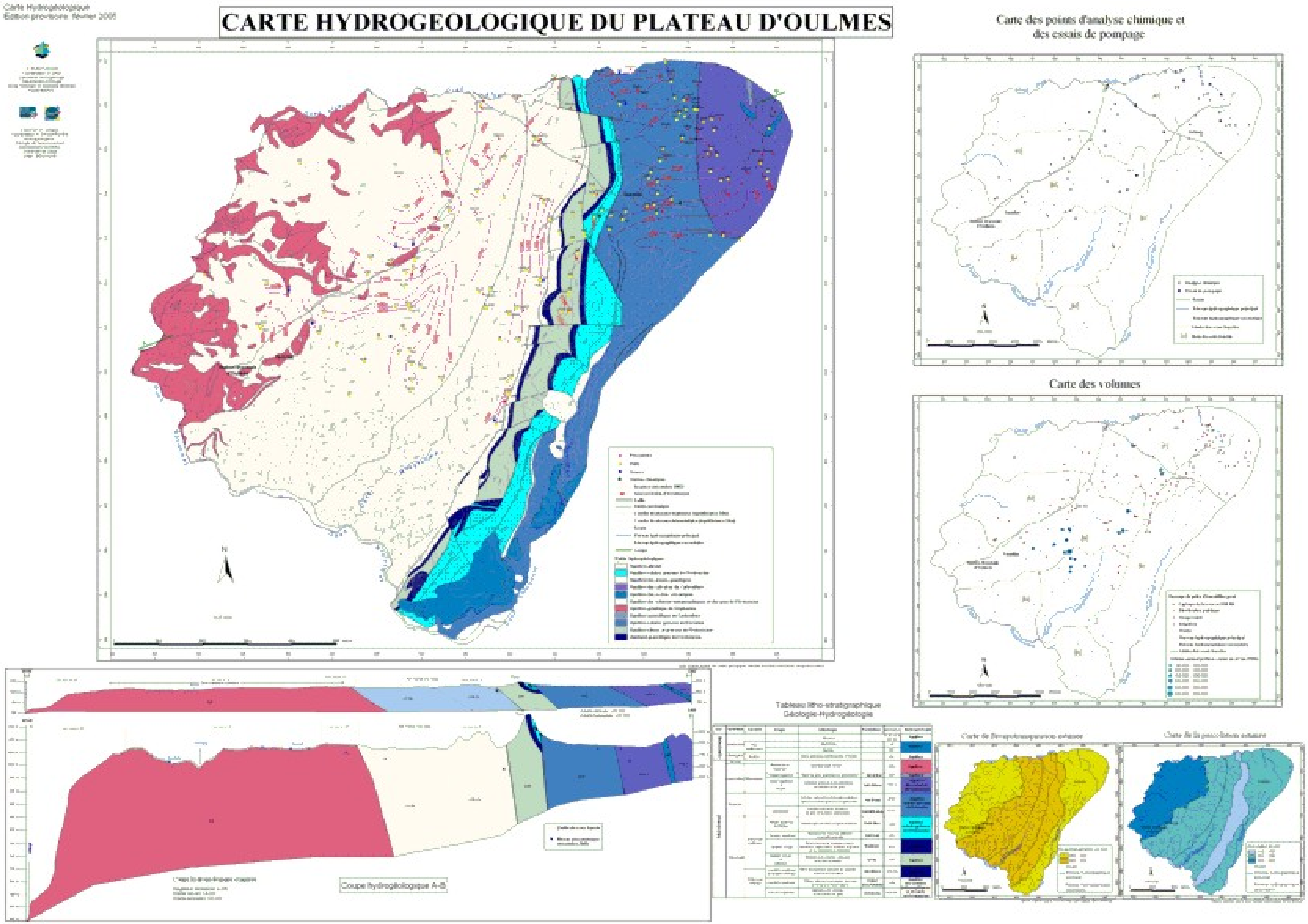
ESRI). Polylines (galleries, isopiestic lines…) and polygons (protection zones, watersheds…) are digitized in the GIS project and their attributes are actively related to the database by a unique number. The hydrogeological database can be consulted starting from the map thanks to an ArcView extension called BDHydro.avx, developed for ArcView 3.2a by our colleagues of the Faculty of Applied Sciences of Mons (Belgium). It opens a window by clicking on one of the element on the map and allows the user to display in the GIS project for example a hydraulic head evolution, a hydrochemical analysis table, the lithological log diagram of a well, etc.

Most of GIS can easily accomplish overlay and index operations, but cannot perform the process-based groundwater modelling functions related to groundwater flow and transport processes. However, coupling a GIS to "process-based" models can provide an efficient tool for processing, storing, manipulating, and displaying hydrogeological data. Even though process-based models do not require the use of GIS, a well-designed database and GIS can significantly reduce the time needed for data preparation and presentation. Modelling groundwater flow and contaminant transport in aquifers represents a spatial and temporal problem that requires integration of process-based models. Each model parameter or variable can be represented on a three- or four-dimensional (x, y, z, and time) information layer. Due to the heterogeneity of the geology, managing these data can be done most effectively through GIS. The process-based models used in hydrogeology include the simulation of steady or transient state groundwater flow, advection, hydrodynamic dispersion, adsorption, desorption, retardation, and multi-component chemical reaction. Very often, exchanges with the unsaturated zone and with rivers are also addressed. In these models, equations based on physical processes are solved.

Application: case of Oulmès (Morocco)

This methodology has been applied in the semi-arid region of Oulmès, located in the Mid-Atlas (Morocco). This study of characterisation (Orban *et al*, 2005) has led to a detailed hydrogeological map. Its development is essentially based on the collection and synthesis of existing data coming from as many as varied sources. A significant field work has been also carried out to check the exactitude of the collected data and to supplement them with some hydrogeological tests (pumping test, sampling for hydrochemical analysis, hydraulic heads...). The hydrogeological map project is composed of a poster and an explanatory leaflet. The poster includes the following components (Fig. 3) : (1) a main hydrogeological map (1/25,000) displaying several layers of information as topography, geology and faults (with lithological formations grouped in hydrogeological units, hydrographic network, localization of wells, springs, piezometers, climatic station, piezometric isolines, arrows indicating the assessed direction of groundwater flow, (2) geological and hydrogeological (with exaggeration of Z-axis) cross-sections displaying the geological structures and the saturation level depth, (3) a lithostratigraphic table showing the correspondences between geological formations and hydrogeological units described as aquifers (high hydraulic conductivity), aquitards (medium hydraulic conductivity) and aquicludes (low hydraulic conductivity) on a lithological basis and (4) four thematic maps showing more specific information (a) two at the scale of 1/50,000 with localization of chemical analysis and pumping tests, delimitation of watersheds, actual exploited volumes (when data are available), use of wells (water supply, irrigation, production, of mineral water…) and (b) two at the scale of 1/100,000 with the estimated evapotranspiration and percolation.

Figure 3: Hydrogeological map of the plateau of Oulmès



The explanatory leaflet is written for a non specialist public and allows a better understanding of the poster. It develops general considerations on regional geography, geomorphology, geology and hydrogeology. It also focuses on specific hydrogeological aspects as local behaviour of the water table, hydrochemistry, hydraulic conductivity parameters.
Potential fields of further use of such a document are as many as varied: qualitative as well as quantitative management of exploited groundwater, evaluation of the pollution risks according to the described direction of the groundwater flow, intervention tool in case of accidental contamination, establishment of new wells for water supply, land-use policy.

Conclusion

The use of Geographical Information Systems (GIS) has grown quickly in groundwater management and research. GIS is now widely used to create digital geographic databases, to manipulate and prepare data as input for various model parameters, and to display model output. A hydrogeological mapping program would allow in the near future to meet efficiently the needs for a more considered and effective management groundwater thanks to the coupling of a Geographical Information System with a complex hydrogeological database. These documents are strongly required by environmental research and management actors. Therefore, the hydrogeological GIS database described in this paper offers capabilities for hydrogeological modelling as well as other hydrogeological studies.

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