18 Mapping Groundwater Resources: Tunisia

General Information

- **Implementing Institution:**
  Ecole nationale d'ingénieurs de Sfax

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- **Implementation Period:** The initiative lasted 33 months, from June 2001 to March 2004.

- **Costs:**
  The total cost of the project, which was supported by the Government of Italy in cooperation with the Ministry of Agriculture of the Government of Tunisia, was some US$4.8 million.

SUMMARY

The integrated study of the groundwater resources of the Sfax region of Tunisia is part of a larger programme for the development of regions of the Sahara and the south of Tunisia financed with the cooperation of the Government of Italy.

The main objectives of the project were to identify the groundwater resources of the Sfax region, to define their quantitative and qualitative characteristics, to develop a rational scheme based on computerized tools for the use and management of these resources, and to provide training for the engineers and technicians of the General Directorate of Water Resources (DGRE).

The methodology developed to reach these objectives was based on a multidisciplinary approach using a variety of exploration techniques. Further studies, field investigations and laboratory analyses were then implemented to complete the data-gathering component of the project. These data were then fed into a database and analysed to determine whether the groundwater systems identified were being overexploited or not and, given predictions for future trends in population growth and water requirements in the region, whether aquifer water could sustainably supply these needs.

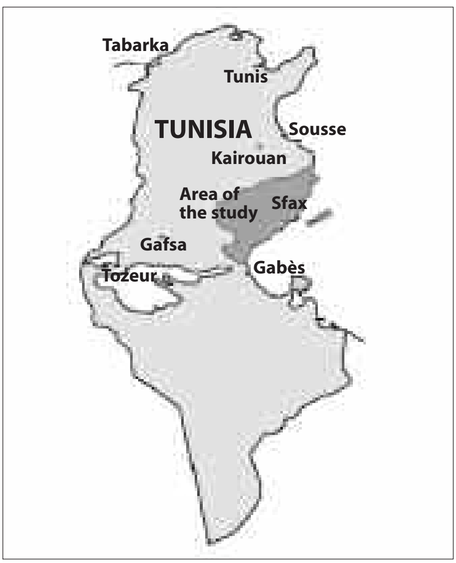

Figure 1. Location map of the project study area.

BACKGROUND AND JUSTIFICATION

In Tunisia, particularly in the south of the country, groundwater is the main water resource and is used by agriculture (80 per cent), industry (10 per cent) and domestically (5 to 10 per cent).

The Sfax region, located on the east coast of the country (fig. 1), has an underground water system composed of a deep confined aquifer and 15 water tables or surface aquifers that are delimited by their respective catchment areas.

Recently, water management authorities have been facing problems associated with declining water quality and increasing demand for water through population and economic growth and the improved standards of living that accompany such changes. Indeed, although some 10 million cubic metres of water were pumped from a deep-lying aquifer each year from 1978 to 1986, between 1987 and 2003, this quantity increased to some 26 million cubic metres (fig. 2).

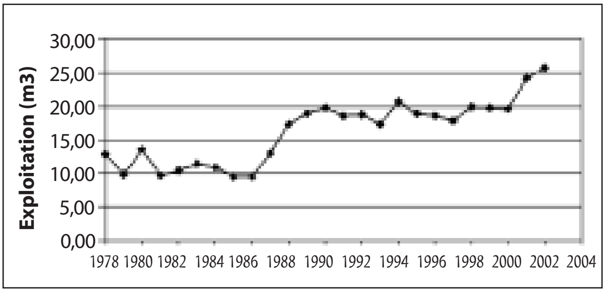

Figure 2. Annual exploitation of the Sfax deep aquifer.

The 15 surface aquifers are also believed to be overexploited, especially near the coast. In addition, the quality of the water that they contain has become degraded owing to their increased exploitation through the construction of new pumping wells, the intrusion of seawater and the infiltration of water that has been used to irrigate crops.

Until recently, the lack of any synthesis, interpretation and archiving of data concerning these aquifers led to the lack of an accurate description of them. This, in turn, led to the region's water resources being undervalued and hence to difficulties in establishing a suitable management plan.

Against this background, the regional water resources management authority was facing a major problem in gathering, synthesizing, interpreting and updating data on the aquifers. In particular, a safe, sustainable yield of both the surface and deep aquifers was not well defined. Since monitoring wells and piezometers (devices used to monitor water flow and measure water pressure in aquifers) are located mainly in the coastal area, the hydrodynamic characteristics of the aquifers are not well defined over their full ranges.

Ensuring the sustainable management of the groundwater resources requires an understanding of the behaviour of water in the underground systems. Owing to the large size of the project area (fig. 1) and the quantity of data needed to characterize the aquifers properly, particularly those that are being highly exploited, the use of computerized tools is necessary. Hence, the first phase of the current project was to construct a hydrogeological database based on locations mapped precisely using a geographic information system (GIS). The combination of these techniques permitted the processing and interpretation of the data gathered during the remainder of the project, including data collected from deep and shallow borings, seismic tests, piezometer readings and geoelectrical profiles.

The ultimate aim of the project is to define both the safe and sustainable groundwater yield for the aquifers of the Sfax region and the areas from which they are recharged. Protecting these recharge areas, for example through soil conservation techniques, and improving the rate of infiltration of water down to the aquifers will help to protect the aquifers themselves. To achieve these aims required the creation of a network for monitoring changes in the quality and quantity of groundwater, the identification of highly vulnerable areas, the establishment of procedures to protect aquifers from sources of pollution, and the establishment of a procedure for the effective management of groundwater data.

DESCRIPTION

First, the existing hydrogeological knowledge of the groundwater situation in the Sfax region was examined. This included searching for all relevant studies carried out by both public and private organizations in Tunisia, including aerial surveys, cartography, climatology, geology, groundwater chemistry, hydrology, geophysics, drillings and piezometric fluctuations.

Beginning in October 2001, a systematic inventory of all deep and surface groundwater wells was also carried out. By May 2002, a total of 13,326 water sources had been inventoried and localized on digitized topographic maps (fig. 3). During this phase of the project, 19 geological maps at a scale of 1:50,000 were constructed on the basis of aerial photographs and calibrated and verified in the field. Each map indicates the precise locations of geological formations and the main faults in the region. These maps were also digitized and stored in the GIS database constructed using Microsoft Access software.

Data collected during the inventory included the identification, characteristics and use of the water wells and an assessment of the quantity of water that they contained. Water level, temperature, electric conductivity and pH were measured *in situ* and samples were also taken from wells provided with pumping equipment so that more thorough chemical analyses could be completed in the laboratory.

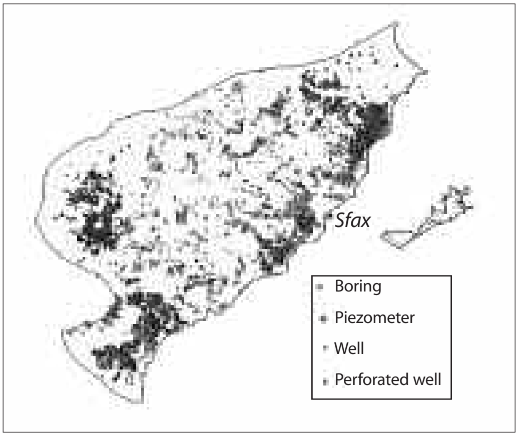

Figure 3. Map of the Sfax region showing the location of all the wells identified during a comprehensive inventory.

Some 3,000 samples of water from pumped wells were analysed for the presence of several elements, including calcium, magnesium, potassium and sodium, as well as bicarbonate, chloride and sulphate ions and trace levels of bromide, iron, manganese and nitrate. Isotopic studies of hydrogen (including deuterium and tritium), oxygen and carbon, which involve analysing the weights of different atoms of the same element, were carried out to determine the recharge rate of aquifers and their dimensions.

Seismic mapping and geoelectrical measurements helped in the construction of completely new maps of the deep reservoirs and surface aquifers, respectively. These maps combined the use of depth and thickness contours with isochrons, or lines linking points at which the water has travelled the same amount of time from a given source. More than 100 geoelectrical tests also permitted the identification of the groundwater zone affected by seawater intrusion.

Seven piezometers were installed at depths ranging from 400 to 800 metres and another 48 at depths from 50 to 120 metres. These piezometers help to monitor changes in water level and water quality.

Analysis and synthesis of the data collected have allowed scientists at the Ecole nationale d'ingénieurs de Sfax to define the aquifer system of the Sfax region.

Deep Aquifer

The deep aquifer has been shown to cover an area of 14,000 square kilometres (including an offshore part of some 3,500 square kilometres). It is contained within bodies of sand varying in thickness, with the maximum thickness in the central part of the basin (fig. 4). Within this aquifer, water flows from northwest to southeast and has a salinity that varies from 3 to 10 grammes per litre. However, in most of the basin, the salinity is less than 4.5 grammes per litre. In the south, around Skhira, however, the salinity is closer to 9 grammes per litre.

Analysis of tritium, an isotope of hydrogen, revealed the absence of an actual refill of the aquifer. This was confirmed using measurements of carbon isotopes, which suggest that the water in the deep aquifer has been there for between 14,000 and 38,000 years without being added to and can be regarded as "fossil" water.

To model the past and future exploitation of the deep aquifer, piezometric readings taken in 1988 were used to calibrate the baseline or steady state.

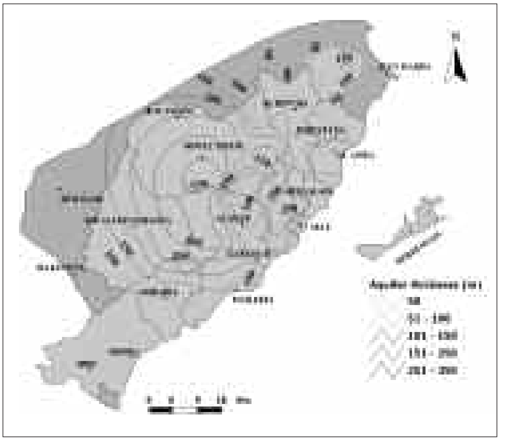

Figure 4. Contour map outlining the thickness of the deep aquifer reservoir under the Sfax region.

The model, developed using FEFLOW software, was then tested using real piezometric readings and water extraction data recorded between 1988 and 2002. These provisional simulations allowed assessments to be made on the state of the aquifer based on projected water demands from industry, agriculture and domestic users until 2030.

Surface Aquifers

Before the present study, the near-surface groundwater system of the Sfax region was thought to be composed of 15 water tables, the limits of which were correlated to catchment areas (fig. 5a). However, using the hydrogeological data obtained from the various surveys and analyses, the whole area was divided into just two water tables (fig. 5b). Water in the coastal aquifer flows towards the sea, while water in the continental aquifer flows inland.

The coastal aquifer, composed of ten of the original water tables, covers an

Figure 5a. Presumed limits of the water tables of Sfax, determined by the limits of watersheds;

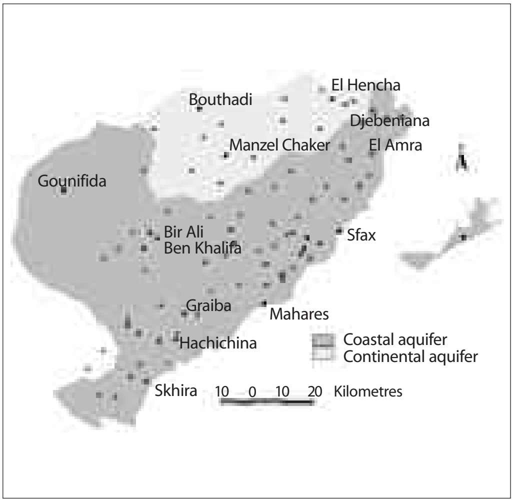

Figure 5b. Limits of the two new water tables, the continental and the coastal, defined by hydrogeological characteristics.

area of 6,477 square kilometres. Its thickness varies from 8 to 60 metres, with an average of 30 metres. Within the aquifer, water flows from northwest to southeast towards the sea and, as it does so, the salinity rises from 0.3 to 23 grammes per litre where seawater intrusion affects the water quality.

As with the deep aquifer, simulations were carried out entering the data collected into the models developed using FEFLOW software. For the coastal aquifer, the baseline was taken to be 1975 and the model was checked against data recorded between 1975 and 2002 and projected forward to 2030. These analyses revealed that, in the case of this coastal surface aquifer, there is already a negative balance between inflow and outflow and that the water table is over-exploited by some 4 million cubic metres a year.

The continental water table corresponds to five of the original watershed aquifers and covers an area of 1,838 square kilometres. It averages 28 metres in depth, with a minimum of 20 metres and a maximum of 42 metres. Currently, this aquifer is underexploited, with a positive balance of 6.5 million cubic metres of water a year. The salinity of the water in the continental aquifer varies from 4 to more than 10 grammes per litre.

A medium-depth aquifer was also identified in three wells 150 metres below the surface. The water in this aquifer has a salinity of between 2.5 and 5 grammes per litre.

PARTNERSHIPS

The project was undertaken in collaboration with both local and national water resource management authorities. Thus, the research interests of the scientists at the Ecole nationale d'ingénieurs de Sfax were carried out considering also the requirements of the groundwater management and planning authorities. The involvement of young scientists in the project should also mean that trained personnel are available for future administration positions.

Replicability

The methodology developed in this study, including the computerization of data, the creation of a database, the utilization of GIS mapping and the development of mathematical models for optimizing the management of water resources, can easily be replicated in other hydrogeological basins in Tunisia and elsewhere. Indeed, a postgraduate student has proposed applying the techniques and methodologies developed for the Sfax region to mapping the hydrogeological system of the adjacent Sidi Bouzid region as his thesis topic.

Policy Implications

The identification of zones where the groundwater is being highly exploited and where groundwater quality is being degraded has permitted the water management authorities to designate protective boundaries, in particular around areas suffering from seawater intrusion and those where piezometric readings are falling. The drilling of new wells for exploiting groundwater is now forbidden in these areas.

A government scheme provides favourable financing arrangements and other inducements to farmers wishing to develop and expand their irrigation systems. However, in order to control such development, each application for an irrigation project is carefully checked against the maps produced during the project and the local groundwater quality and availability. Thus, GIS inputs and other data supplied by the project are playing a major role in the decision-making process for the approval or rejection of these schemes and are assisting the sustainable development of the region.

Lessons Learned

During the inventory of the wells, some farmers objected to providing information about their operations and water consumption practices even though the aims of the project were explained to them in an effort to gain their confidence. Therefore, it was necessary to attempt to verify much of the data collected in this way.

Although the objective of the project was not necessarily aimed directly at involving the public, as a consequence of the general scarcity of water in Tunisia, the media were interested in broadcasting updates of the findings and recommendations. Thus, the Tunisian public can be considered to be aware of the necessity to preserve and protect the nation's water resources. Improper water-use practices relate mainly to the lack of financial resources.

Impact

The project provided an assessment of the available groundwater in both the deep and surface aquifers of the Sfax region. The comparison of this resource in relation to the needs of the agricultural and industrial sectors and domestic use has permitted the development of scenarios for the optimal exploitation of these water sources with the help of the mathematical models. These models depend on the wealth of information now logged into a specially created database containing the locations of wells mapped by GIS and the chemical components of the water that they contain. In other words, the collation and analysis of this data have permitted the better management of the region's water resources and have allowed decisions to be made concerning their safe and sustainable exploitation until at least 2030. Such sustainable utilization of resources is the basis of economic, environmental and social success. Environmental sustainability has been ensured by the implementation of a development plan that aims to prevent the deterioration of water quality by the intrusion of seawater into the coastal surface zone or by the intensive use of agrochemicals in sensitive areas.

Another major achievement of the project has been to ensure that the studies and measurements are continuing even after the contractual period of the project has ended. A unit has been established to collaborate with the local administration to continually refine and update the data.

During the period of the project implementation, many training workshops were organized and attended by DGRE technicians and engineers as well as young researchers from the University of Sfax. Subjects covered included the use of databases, digitizing maps and GIS use, modelling, boring and well test activities and interpretation, geophysical interpretation, and chemical and isotopic analyses and interpretation. Thus, there is now a nucleus of well-trained personnel in both academia and the public sector who will continue to apply the principles of sustainable water exploitation throughout their careers.

Future Plans

Three doctoral projects have been proposed by the University of Sfax concerning: the follow-up of the qualitative and quantitative survey of the region's water tables; the characterization and modelling of seawater intrusions into the coastal aquifer; and the construction of a model for water resource management in the region. These studies will add to the fundamental knowledge required for the sustainable development of the region's water resources.

There are also plans to begin collaborations with university researchers in both France and Spain.

Publications

During the project period, ten master's degrees were awarded to students:

Ben Akacha, M.: Study of the mio-plio-quaternary series and tectonic and morphologic evolution in the region of plateau of Agareb and Sfax plain;

Bouaziz, S.: Construction of a geographic information system for the study of the geology of Sfax;

Ghribi, R.: Geomorphologic and neotectonic study of the exoreic wadis of the meridional part of Sfax plain;

Hajji, S.: Modelling of the deep aquifer of Sfax;

Hassine, S.: The management of the water resources of the Chaffar water table;

Karray, I.: Study of the environmental vulnerability of the Skhira water table;

Smida, H.: Contribution of the GIS to the study and management of water resources: Case of the Chaffar water table;

Trabelsi, N.: Construction of geographic information system for the deep aquifer of Sfax;

Trabelsi, R.: Hydrogeology of the phreatic aquifer at the North of Sfax: Mineralisation and marine intrusion evolution;

Triki, I.: Analysis and optimisation of Sfax water tables monitoring network.

Case Study Prepared by:

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Project Participants:

Hamed Ben Dhia, director of the university team.

Moncef Zairi, technical coordinator of the university team: Calibration and verifications of mathematical models, training field teams and writing reports.

Samir Bouaziz, **Raouf Ghribi** and **Saloua Bouaziz**: Used aerial photos to produce 19 geological maps at a scale of 1:50,000.

Mourad Bedir and **Nabil Ghorbel**: Analysed and reinterpreted the existing seismic and electrical geophysical data. N. Ghorbel also verified and interpreted geoelectrical data.

Kamel Zouari: Conducted the isotopic investigations.

Samia Tagina: Coordinated the field teams for inventorying the wells and collecting other data.

Hamda Trabelsi: Helped to supervise field activities and hydrogeological data processing.

Monem Kallel and **Jalel Bouzid**: Carried out chemical investigations.

Ali Chkir and Mohamed Mahfoudh: Studied the institutional and legal aspects of managing the water and the evolution of water requirements.

All the above-mentioned university team members participated in the training of DGRE technicians and engineers.

Rouaida Trabelsi, **Habib Smida**, **Ismail Karray** and **Soumaya Hajji**: Conducted the field work, including the inventory of the wells and groundwater sampling and analysis, and processed the data in the database.