Collecting aggregated groundwater data to identify highly stressed aquifers worldwide

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Abstract Assessment of global groundwater resources is the core mission of the International Groundwater Resources Assessment Centre (IGRAC) working under the auspices of WMO and UNESCO. In 2006, IGRAC set up a project about monitoring groundwater resources on a global scale to assess the current state of groundwater resources worldwide and its expected trends, and identify highly stressed or underexploited aquifers. Three important aspects of this project are: (1) setting up a network of regional and national groundwater experts committed to providing aggregated groundwater monitoring data; (2) a user-friendly web-based application for collection, processing, storage and dissemination of groundwater monitoring information; and (3) the choice of adequate groundwater variables, both observed and derived. This paper focuses on the architecture and functionalities of the innovative web-based application released and discusses the choice of (derived) variables serving various user groups requesting large scale regional and global groundwater related information (e.g. scientists, international agencies, policy/decision makers and financial institutions).

Key words groundwater monitoring; network; global assessment; variables
International Groundwater Resources Assessment Centre (IGRAC)

INTRODUCTION

The International Groundwater Resources Assessment Centre, IGRAC, facilitates and promotes worldwide exchange of groundwater knowledge to improve assessment, development and management of groundwater resources. One of its core projects is the global assessment of groundwater resources. Currently, the state of the groundwater resources on a global scale is estimated by scientists using the following approaches: (1) hydrological models which simulate the hydrological cycle and approximate the groundwater recharge to the shallow aquifers (WaterGAP Global Hydrology Model (WGHM) of Döll *et al.*, 2003, 2008); (2) remote sensing data also for the estimation of groundwater variables like GRACE (Gravity Recovery and Climate Experiment, Rodell & Famiglietti, 2001; Ramillien *et al.*, 2004); and (3) terrestrial groundwater monitoring, usually providing point measurement of groundwater variables. Regarding the third approach, global terrestrial groundwater statistics are currently available only at a country aggregated level (Global Overview of IGRAC) which present information at a global scale for about 80 variables and parameters. Unlike other variables of the water cycle like river discharge (the work area of Global Runoff Data Centre, GRDC) and precipitation (the work area of Global Precipitation Climatology Centre, GPCC), there is as yet no systematic monitoring of the groundwater component on a global scale.

Assessment of the groundwater component through the collection of groundwater data on the global scale implies an intensive collaboration with national institutes and experts as those data are often collected and archived at the (sub)national level. This approach is the one chosen by IGRAC and complements other international initiatives which focus on modelling and remote sensing techniques. The Global Groundwater Monitoring Network project (GGMN) started in 2006 and the following main activities were defined:

(a) Setting-up a network of regional and national groundwater experts committed to provide aggregated groundwater monitoring data.
(b) Designing a user-friendly web-based application for collection, processing, storage and dissemination of groundwater monitoring data and information.
(c) Choosing adequate groundwater variables to be reported by the members of the people network using the web-based application.
(d) Choosing derived variables or indicators, in collaboration with the end-users, describing the state of the groundwater resources and expected trends to be published as online maps.

The first activity, setting up a people network of committed regional/national groundwater experts acting as national reporters, is considered the main challenge of the GGMN project. Incentives are important to encourage the participation of national experts. Obstacles like human capacity, mandates of collaborating institutes and public availability of data are taken into consideration.

In former papers, several activities of the GGMN project were already discussed. An inventory of current data sets, programmes and networks with a linkage to GGMN was presented (Kukuric & Vermooten, 2007), comprising groundwater data sets directly available for GGMN, an organisation with extensive experience in collection procedures worldwide and existing international and regional relevant people networks. Also global monitoring variables, aggregation procedures and an introduction to the GGMN web-based application was described. In Kukuric & van Vliet (2008), the focus was on setting up the African Groundwater Network as an integral part of the Global Groundwater Monitoring Network. In the current paper, the first section focuses on the description of the web-based application, its architecture and functionalities. In the second section, a choice of adequate observed and derived variables required to support various user groups (e.g. scientists, international agencies, policy/decision makers and financial institutions) is discussed.

A WEB-BASED APPLICATION FOR GGMN

A Web 2.0 application

Web 2.0 or "new internet" refers to the new generation of internet developments worldwide in which information sharing, communication, interoperability and collaboration through the World Wide Web play an important role (see http://en.wikipedia.org/wiki/Web_2.0).

The web-based application of GGMN can be considered as a Web 2.0 application as it uses the internet as a platform to foster information exchange and collaboration between groundwater experts worldwide. Requiring only a browser and access to the internet, it is developed for the purpose of supporting the network of people during the reporting and sharing of data and information related to the quantity and quality of groundwater resources (change in groundwater levels, abstractions, ECs, etc.). The users of the application, referred to as reporters, are members of a groundwater expert network set up in the framework of the GGMN project.

Data ownership

Since groundwater is often seen as a strategic resource, data ownership needs to be taken into consideration when collecting and sharing groundwater data. Raw data on groundwater level changes, groundwater quality and groundwater abstraction are seldom publically available and remain protected in national, state or local data repositories. These repositories vary from country to country, ranging from paper archives to advanced, quality controlled databases (Jousma *et al.*, 2004). Data ownership and differences in quality of national databases are taken into account while defining the GGMN web-based application. Its purpose is not to collect "raw data" but to take advantage of the national expert's knowledge to share "aggregated data" (Kukuric & Vermooten, 2007). The aggregated data and information are stored in a database and the country expert retains the control of the country data. This way often disputed "delivering" of data to an international organisation is weakened if not completely dismissed.

Basic features of the application

The web-based application is realized using the Flex 2 technology of Adobe and the existing map functionalities of online Yahoo Maps. This thin-client application has an interactive, self-explanatory and user-friendly interface. The basic features currently available in the web-based application are described below and are visible in Fig. 1. As explained before, as groundwater experts from around the world are invited to use the application, it was based on the principle that it should be straightforward and easy to use with an average broadband internet connection.

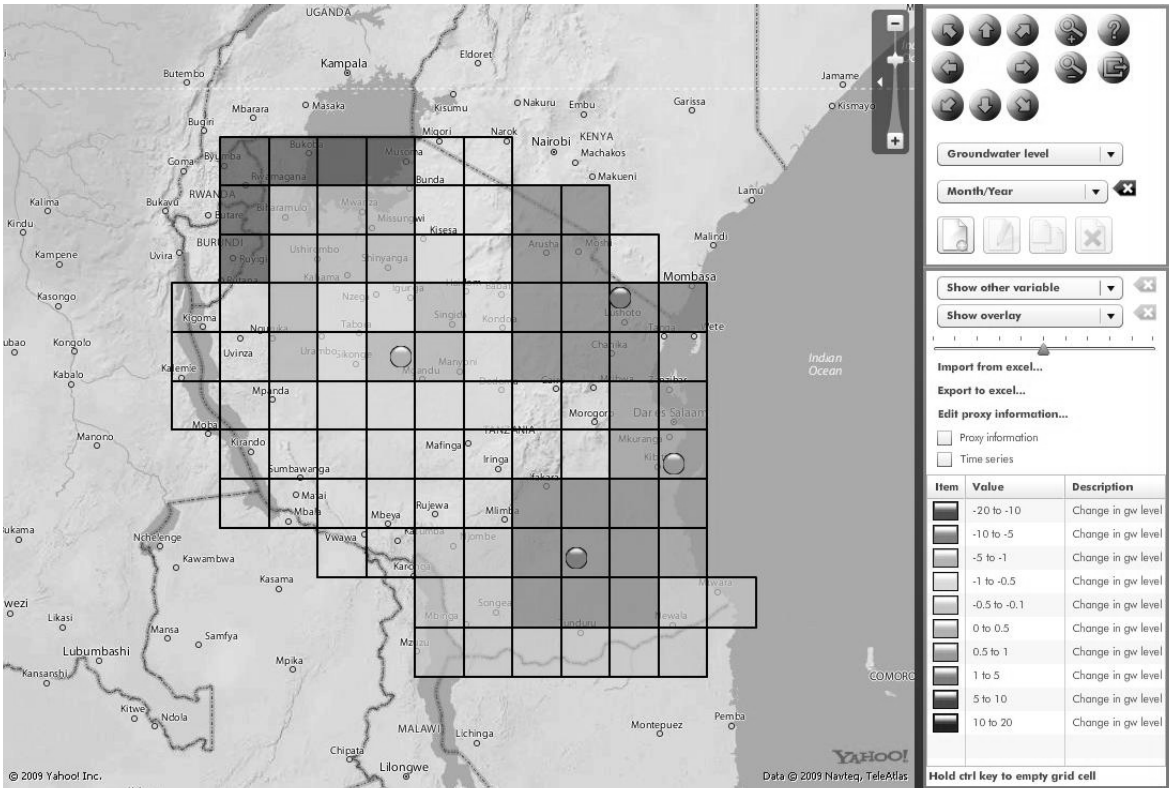

Fig. 1 Features of the application, Tanzania as example (the data shown in the graph is fictitious).

Regarding the input of variables, two features are available:

– Grid-based input of aggregated data for cells of 1 × 1 degree (roughly 100 × 100 km). This grid approach as opposed to polygon based data input was chosen because of its compatibility with other available global gridded data sets like precipitation grids, population grids, etc. Currently global precipitation grids are for example available at the GPCC (gpcc.dwd.de) at different scales (0.25, 0.5, 1.0 and 2.5 degree cells). Likewise, some global hydrological models are based on a grid approach (0.5 degree resolution) (Döll *et al.*, 2003).
– Point-based input of proxy data. Proxy data is data that indirectly gives information on a required variable for which few or no data exists. For example precipitation data can be considered as proxy data for potential groundwater recharge. Other examples of proxy data for GGMN are snow cover and population density. These proxy data can be easily imported in the application though a database file, added point by point by the reporter and edited online.

Regarding the output of the web-based application:

– Proxy data can be exported to database files to be edited or archived in systems of national and regional experts.
– Global gridded data sets can be drawn from the application to be published as online global maps, shared and combined with other global data sets.

Regarding supporting features:

– The standard background map is a Yahoo map in Mercator projection (http://maps.yahoo.com), adjusting its resolution automatically to the zooming of the user.
– Any available background map with a known projection can be added to the application and its transparency adjusted. These maps can be global maps like the Whymap "Groundwater resources of the world" map (www.whymap.org), monthly gridded precipitation maps,

regional maps or national maps like country hydrogeological maps or groundwater contour maps. This feature is aimed at assisting the national/regional expert in the aggregation procedure.
– Beside the fact that data can be visualized geographically for one specific month, changes through time can also be visualised using the time series graphs feature (Fig. 2). Both proxy data and grid data can be plotted in a time series to observe trends.

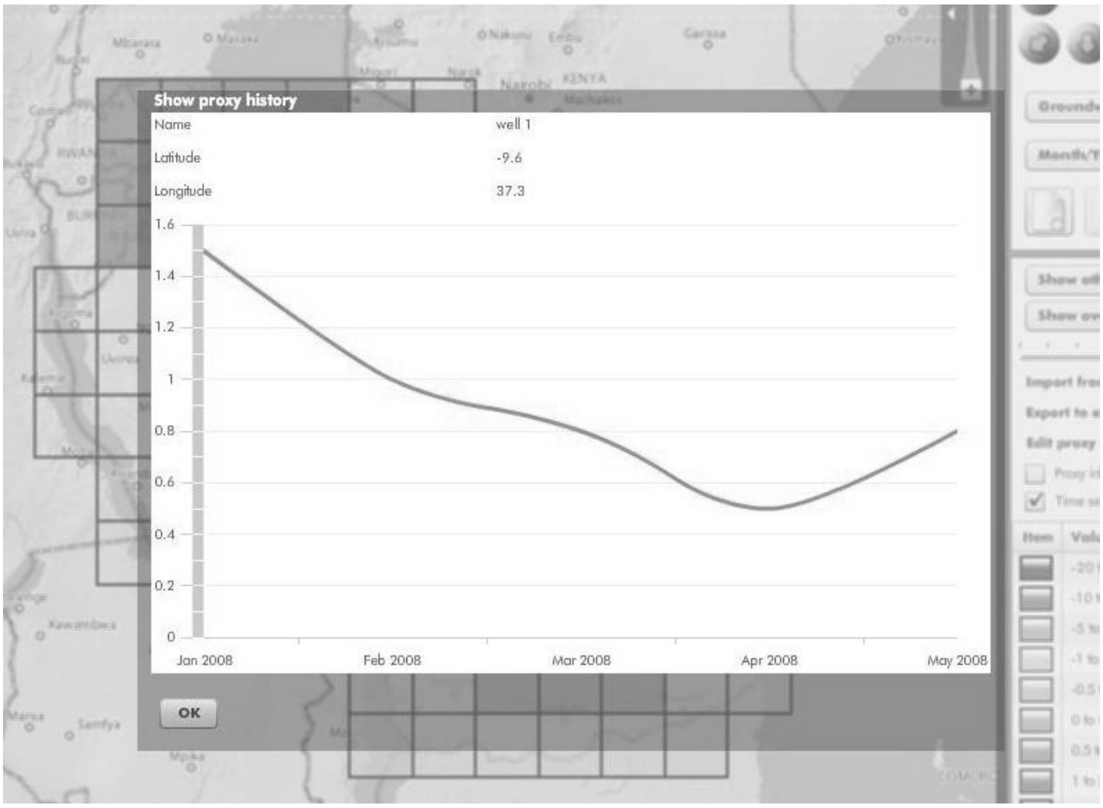

Fig. 2 Example of time series for a representative well in Tanzania as presented in the web-application (the data shown in the graph is fictitious).

Procedure for the country reporter

When using the application, the groundwater country reporter should follow the 4 basic steps described below:

– Step 1: Selecting the country and plotting the grid. The land is selected automatically, when the national expert logs in the reporting application. The grid is automatically generated when choosing a reporting month.
– Step 2: Adding relevant background maps to assist in the aggregation procedure.
– Step 3: Adding the proxy data in order to alleviate estimation of groundwater variables.
– Step 4: Filling out the grid per groundwater variable per month. The reporter uses its expert knowledge, the proxy data and the background maps to assign a representative value to each grid cell. This is called the aggregation procedure.

Offline version of the application

To serve countries and organisations with poor or non-existent internet connections, a special offline version of the application was developed. This offline version consists of a simple Excel file which can be filled out by the country expert and returned to IGRAC for processing.

Future development of the application

The GGMN application will be further developed using the feedback from the international groundwater expert network. It is essential that it remains user-friendly and simple so that it appeals to a large community of groundwater experts. Efforts are currently focusing on adding features for transboundary harmonisation and compilation of global data sets like online maps showing a regional change of groundwater variables in time.

CHOOSING ADEQUATE DERIVED VARIABLES

The overall aim of collecting groundwater monitoring data at a global scale is to assess the state of the groundwater resources worldwide and act as a complementary assessment approach to global hydrological models and remote sensing data. A sound global assessment will reveal highly stressed aquifers worldwide caused by over-exploitation and/or groundwater pollution and their changes in time.

End-users of product

The main end-users for which the global scale information is most relevant are the following:

– The scientific community needs terrestrial groundwater monitoring data to calibrate, verify and improve global or regional assessments based on remote sensing data sets (i.e. GRACE) and global hydrological models (i.e. WGHM, PCR-GLOBWB).
– International agencies require information for global water resources assessments published for decision and policy makers at the international level (World Water Assessment Program WWAP, World Resources Institute, UNEP's Global Environmental Outlook, FAO's Aquastat, etc.). This information is especially valuable with regard to poorly or ungauged basins.
– Financial institutions like the World Bank (Global Environmental Facility), Asian Development Bank, African Development Bank and other regional development banks need derived information revealing the current state of the groundwater resources and expected trends for their prioritization of funding related to (ground)water projects.

A paradox exists because these end-users are different from the national groundwater experts who report to the GGMN application. Indeed the scale at which data is collected, 1 degree cells (roughly 100 × 100 km) is too large to be of any direct use to the country expert at the national level, unless the country is very vast like Canada, Russia, China, USA or Brazil. Indirectly, however, reporting their national groundwater situation could reveal the good or poor status of aquifers in their country, whether they are highly stressed or underexploited therefore attracting funding to mitigate groundwater problems or to develop unexploited groundwater resources. In this way national groundwater experts can indirectly benefit from the global maps compiled with their cooperation.

Final product and derived variables

A derived variable (or indicator) is a combination of a variable with other variables, other parameters or other pieces of information. It generates new information and knowledge for different end-users. When selecting suitable derived variables, the following prerequisites are important to consider: the availability of data (from GGMN and other sources) to calculate the derived variables and the commitment of the national groundwater experts to share the basic data and report to the GGMN application. The quality of the final product highly depends on the amount of collaboration and the quality of the data and information reported by the national experts. Therefore the variables reported to the GGMN application should be based primarily on the standard variables monitored in each country. The groundwater variables which are currently mostly reported are groundwater levels and abstractions in wells, discharges at springs, base flows in rivers and basic quality parameters (EC, TDS, chloride, nitrate) (Jousma *et al.*, 2004). Hence priority is given to report these variables in the GGMN application.

Keeping these prerequisites in mind and the diversity in end-users, derived variables can be defined. First of all, because of the different needs of the end-users, it is important to produce global data sets of the basic variables reported by the country expert.

– Representative monthly change in groundwater levels per grid cell. Because of the grid resolution, it is not feasible to report the absolute groundwater level as differences in absolute groundwater level within one grid cell can be very large in high relief areas and would not give a sound representative value.
– Representative groundwater abstraction per month per grid cell.
– Representative EC (Electrical Conductivity) per month per grid cell.

These global data sets are best suited for the first group of end-users, the scientific community. For their research related to global or regional assessment, the scientific community usually prefers to obtain raw data (point level) instead of aggregated data (grid level) but in the light of the challenging task to set up a network of groundwater experts reporting to the GGMN application, this is not feasible. Indeed most of the national and local data repositories are not publicly available. As explained in the first section, by only asking for aggregated groundwater data, barriers that prevent the national experts sharing data are mostly removed. The national expert is therefore invited to report aggregated data per grid cell of 1 degree and not raw point data.

Serving end-users from the international agencies and financial institutions, asks for flexibility in defining derived variables. IGRAC intends to choose these derived variables in collaboration with the end-users. The derived variable should be dedicated to the problem or question of policy and decision makers. Hydrogeological information will in most cases be integrated with socio-economic, agricultural, hydrological or meteorological information to serve this target audience and to result in action. Currently there is no official international agreement on derived variables or indicators to be used when reporting to policy and decision makers about the state of the groundwater resources. Instead there are many (ground)water indicators developed by different organisations in different programmes (WWAP, FAO, MDG, EEA). The Groundwater Indicators Working Group, UNESCO, IAEA and IAH (International Association of Hydrogeologists) recently published a list of 10 indicators, e.g. "renewable groundwater resources per capita" or "total groundwater abstraction divided by groundwater recharge" (UNESCO, 2007). One of the Millennium Development Goals indicators refers to water, "surface water and groundwater withdrawal as percentage of total actual renewable water resources". Also, 64 indicators were developed within the framework of the WWAP, from which nine focus on the available water resources and need groundwater data as input (WWDR II, 2006). Additionally, often new sophisticated indicators are invented in research programmes and projects without verifying whether the basic data to calculate the indicator is existent and accessible.

Suitably derived variables will thus be chosen in collaboration with the end-users and considering the fact that the basis of the global data sets provided by GGMN and used for the calculations of derived variables remains data that is easy to report by the national groundwater experts. For example, regarding groundwater quality, a derived variable could reveal deviations in quality with respect to existing groundwater quality standards like the Groundwater Daughter Directive of the European Water Framework Directive or WHO standards. In the GGMN project, regarding groundwater quality, priority is given to report EC implying that the derived variable published as a global data set will have the EC variable as one of its components.

CONCLUSIONS

An innovative web-based application was developed based on the principle that its simplicity, clear information and data ownership are provided to ensure the commitment of the groundwater community in supporting and joining the Global Groundwater Monitoring Network, GGMN. Variables to be reported to the GGMN application should be easy to obtain and to share by the national experts. Aggregated variables are therefore preferred as opposed to local raw data.

The product, grid-based global maps of variables and derived variables, should serve the end-users. Collaboration with these end-users about adequate derived variables is therefore essential. Results of the GGMN project will enable the international community to assess the state of the groundwater resources worldwide, its expected trends and to identify highly stressed aquifers that deserve its attention.

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