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NATIONAL GROUNDWATER MONITORING PROGRAMMES

A global overview of quantitative groundwater monitoring networks

Produced by IGRAC (International Groundwater Resources Assessment Centre), 2020

In cooperation with WMO and with contributions of many national water authorities.

International Groundwater Resources Assessment Centre

IGRAC facilitates and promotes international sharing of information and knowledge required for sustainable groundwater resources development and management worldwide.

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United Nations Educational, Scientific and Cultural Organization

International Hydrological Programme

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NATIONAL GROUNDWATER MONITORING PROGRAMMES

A global overview of quantitative groundwater monitoring networks

Groundwater is a vital natural resource, being increasingly under pressure of climate change and human activities. We need to monitor the invisible groundwater in order to use and protect it properly.

This document provides an overview of quantitative groundwater monitoring networks at national scale. It is prepared to encourage sharing of monitoring experience, assist in improvement of monitoring and data processing and increase awareness of a general lack of groundwater monitoring.

Rationale

Groundwater is the most abundant freshwater resource on the planet: it provides almost half of all drinking water worldwide, about 40% of water for irrigated agriculture and about one third of water required for industry. It sustains ecosystem and maintains the baseflow of rivers. Groundwater is a critical storage element for climate-change adaptation, it prevents land subsidence and seawater intrusion. Yet, aquifers (being invisible) are often insufficiently understood and poorly managed.

State of aquifers (both quality and quantity of groundwater) is changing in time due to change of various environmental processes (e.g. change of precipitation pattern) and human impacts (i.e. change of land cover, groundwater abstraction). Groundwater assessment is not complete- and no predictions can be made without an analysis of historical measurements (change in time). In short: we can't manage, what we don't measure.

Groundwater is monitored around the world by measuring groundwater levels, groundwater abstraction rates, spring discharge and groundwater quality. Globally, there is no sufficient knowledge about the state and trends of groundwater resources, primarily due to:

- insufficient monitoring
- limited accessibility to monitoring data/outcomes

Monitoring of groundwater is more challenging than monitoring of surface water (river and lakes): initial investments (e.g. drilling a borehole) are larger, spatial representativeness of monitoring points (due to hydrogeological heterogeneity) is smaller and assistance of remote sensing (so helpful to surface water observations) is limited.

Groundwater monitoring data is also less accessible than those of rivers and lakes, again partly due to less visible nature of aquifers.[1] Surface water monitoring data are often available per catchment, even for those internationally shared, thanks to numerous international cooperation agreements. Groundwater monitoring data are usually available at the national level, less often per aquifer and in very few cases per internationally shared aquifer (as a part of an international agreement).[2] Fortunately, there is a clear positive trend: more and more countries are making groundwater monitoring data available online or on request.

This document contains a global overview of national quantitative groundwater monitoring networks. The purpose of the overview is to:

- provide an integrated and structured information on groundwater monitoring programmes worldwide;
- serve as the best entry point to information on state and trends of groundwater resources per country, globally;
- assist in improvement of national monitoring programmes, especially of data processing and usage by learning from other programmes;
- encourage sharing of groundwater data and information by countries and their cooperation on transboundary groundwater resources; and
- Increase visibility of groundwater monitoring and increase attention to state of groundwater resources.

This overview includes only a quantitative aspect of groundwater monitoring. IGRAC is working on an overview of groundwater quality monitoring networks as well.

Fig. 1 – Groundwater meter near Oranjewoud, by: Udo Ockema

Groundwater monitoring from a global perspective

Groundwater is a local resource but one with a global impact. Accordingly, monitoring is one of core IGRAC activities. IGRAC works under auspices of World Meteorological Organisation (WMO) and looks after groundwater change and -monitoring in most of WMO programmes and networks. Already in 2004, IGRAC produced the World-wide Inventory on Groundwater Monitoring with the objective of revealing the state of groundwater monitoring worldwide and identifying needs for monitoring information and related guidelines. Subsequently, a Guideline on Groundwater monitoring for general references purposes was produced in 2008, focusing on the early stages of groundwater monitoring, often characterized by limited hydrogeological information, financial resources and/or institution

[1] Changes in groundwater water quality and quality are more difficult to notice and to measure; monitoring data are therefore sometimes seen as strategic (especially in an international context) and/or having a distinct economic value.
[2] While more than half of large aquifers in the world are internationally shared.

capacity. In 2012, the Global Groundwater Monitoring Network (GGMN) programme was launched, with the objective of improving quality and accessibility of groundwater information and subsequently the knowledge on the state of groundwater resources. The GGMN Programme (www.un-igrac.org/ggmn) consists of two components:

- The GGMN People Network
- The GGMN Portal

In meantime, the programme involved groundwater specialists (People Network) from more than 50 countries, whereas the GGMN Portal is used for storage, processing and dissemination of groundwater data worldwide.

Fig. 2 – GGMN workshop for South-East Asia

In the constant process of populating the GGMN with new monitoring stations and updated measurements, valuable information was collected on national groundwater monitoring programmes around the world. At some point it became obvious that this informations needs to be augmented, structured and made available as an overview to everyone interested in groundwater.

Fig. 3 – GGMN portal

The content of the overview

The core of this overview are the "Country Profiles": each national monitoring network is presented separately in an uniformly structured manner to allow easy browsing, comparison and further analyses. Information collected per country is organised in four sections dedicated to:

- Institutional settings and purpose: Institution/s in charge of groundwater quantity monitoring and purpose of the network/s;
- Characteristics of the network: number of monitoring stations, density of the network, frequency of monitoring, manual or automatic measurement, telemetry;
- Processing: methods used to analyse data collected to create meaningful information (e.g. statistical methods to produce monthly groundwater level maps); and
- Dissemination: how data and information are communicated to the public (e.g. website, reports, free downloading of data).

When any of these sections is not presented, it means the related information is not available and/or not publicly accessible online.

The following section provides an insight in the preparation of this overview, which included correspondence with the countries to request information and/or to check its validity when collected elsewhere. A section on analysis gives the first figures about the state of groundwater monitoring globally. Hopefully it will trigger a discussion, further analysis and eventually improvements (in network design, processing of monitoring data, dissemination, etc).

How was this overview is prepared?

The first preparation step was a desk research about groundwater monitoring on a national scale, including all countries (108) where information on this matter was available. The research showed that for 27 countries[3] one of the following holds:

- there is no groundwater monitoring programme or network managed either on a national or local level;
- there are institutions with the mandate to monitor groundwater quantity, but it is unknown if there is a monitoring network in operation;
- there is/used to be a groundwater monitoring network programme, but it is unknown if the network is still operational;
- there is a plan to implement a groundwater monitoring network, but it is not clear when it will be implemented;
- there was only one source of information (non-official) about the existence of the network; or
- only groundwater quality monitoring activities were found.

In some cases, the language barrier seemed to be the reason why no information on monitoring networks could be found (the search was done in English, Spanish, Portuguese, French and Russian).

At the end of 2018 IGRAC, sent an open request to 62 countries that were not included in the research yet, asking for information about groundwater level monitoring. Apparently, this request did not include all countries in the world since no contact data/email was found for all of them. Institutions approached were mostly ministries, water agencies and hydrometeorolog-

[3] Angola, Belize, Benin, Bhutan, Burkina Faso, Burundi, Chad, Cameroon, Cote d'Ivoire, D.R. Congo, Djibouti, Ecuador, Ethiopia, Guatemala, Guinea, Honduras, Iceland, Kenya, Mali, Mauritania, Nicaragua, Panama, Senegal, Singapore, South Sudan, Sri Lanka, and Togo.

ical services, geological surveys, or similar. WMO also kindly sent a letter to support GGMN activities to all member states. However, from 62 contacted countries only 10 replied and only 4 provided information by filling out a form provided by IGRAC.

Eight Latin American countries were contacted via the Regional Center for Groundwater Management in Latin America and the Caribbean (CeReGAS) and four of them sent the filled-out forms back. In future, more regional centres should be involved in collecting information from national authorities.

Subsequently, 81 profiles were created for the countries with an established groundwater monitoring programme or network, or with plans to establish one in the short- or mid-term.[4]

In 2020, IGRAC sent to a monitoring network country profile to corresponding organisations, with a request to check validity and completeness of the information in the profiles. More than half of the organisations (48) replied by either accepting or updating the profiles.

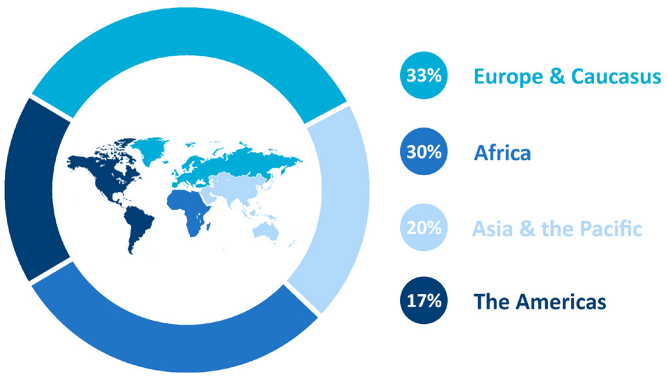


Fig. 4 – National monitoring networks per region (in %)

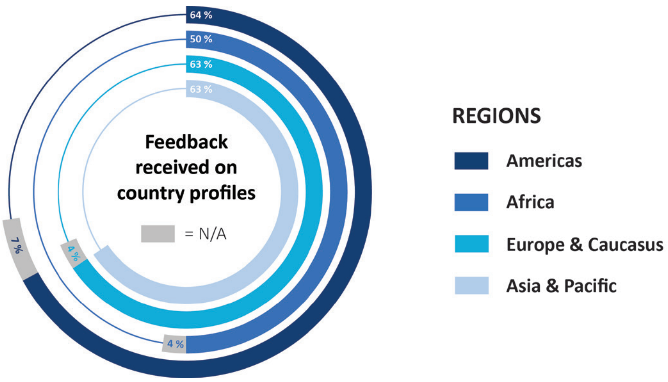


Fig. 5 – Feedback received on country profiles per region (in %). N/A - the request mail bounced

Analysis of results

I. TYPE OF NETWORKS

Groundwater monitoring networks found can be divided into three categories:

1. **National** - the network is a country-wide and generally, one organisation is responsible for its management;
2. **Regional/local** - a country has several networks with different coverages and organizations managing them; and
3. **Project-based** - the network was established as a result of a funded project (usually has a local coverage).

In several cases a regional/local network was established as a part of a funded project supported by an external party (intergovernmental organization, international development bank, etc.), as it is the case of Afghanistan and El Salvador. However, in some cases, the monitoring stops after a project ends, as it is the case of Mali's groundwater monitoring network.

Groundwater monitoring is centralised in most of the countries. Otherwise, federal states, regions or counties often have their own programmes. If so, data collected is not necessarily reported to the central government for various reasons. For example, in Germany, each federal state is responsible for collection, processing and dissemination of data, while in Bolivia there is no national groundwater monitoring programme, only a several local networks are in place.

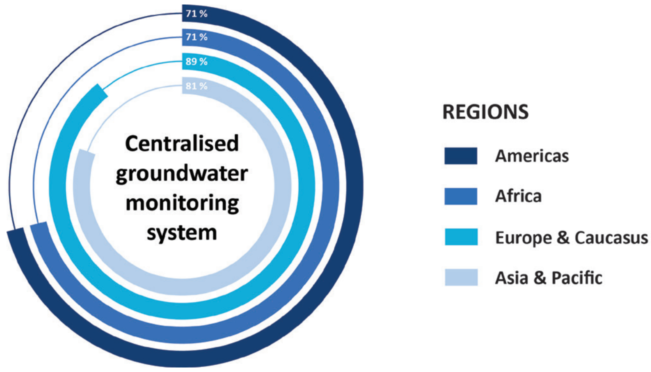


Fig. 6 – Countries with a centralised monitoring system, per region (in %)

II. PURPOSE OF THE NETWORK

The most frequent purpose of a national network is the reference monitoring i.e. to assess temporal and spatial variations of groundwater with respect to other environmental processes and human activities. Also occasionally mentioned objectives of national networks include the contribution of scientific information and the monitoring compliance with regulation or standards. An example of a specific purpose at a national level is the Climate Response Network managed by the US Geological Survey: to monitor the effects of droughts and other climate variability (more information on page 32)

[4] Afghanistan, Algeria, Argentina, Australia, Austria, Bangladesh, Belgium, Bolivia, Botswana, Brazil, Cambodia, Canada, Chile, Colombia, Costa Rica, Croatia, Czech Republic, Denmark, El Salvador, Eswatini, Estonia, Finland, France, Ghana, Germany, Greece, Guinea Bissau, Hungary, Italy, India, Indonesia, Iran, Ireland, Jordan, Korea, Latvia, Lesotho, Lithuania, Luxembourg, Malaysia, Malawi, Mauritius, Morocco & Western Sahara (Moroccan Sahara), Mexico, Moldova, Mozambique, Myanmar, Namibia, Nepal, Netherlands, New Zealand, Niger, Nigeria, Norway, Pakistan, Paraguay, Peru, Poland, Portugal, Russian Federation, Rwanda, Serbia, Sierra Leone, Somalia, South Africa, Sudan, Spain, Sweden, Switzerland, Tanzania, Thailand, The Gambia, Tunisia, Uganda, United Kingdom, United States, Uruguay, Venezuela, Vietnam, Zambia, and Zimbabwe.

III. FREQUENCY AND METHOD OF MONITORING

Frequency of monitoring varies greatly. Countries reported frequencies of: 15 min, hourly, daily, weekly, monthly, and several times per year, including combinations of them. More frequent monitoring (daily or more) are associated with the use of automatic networks.

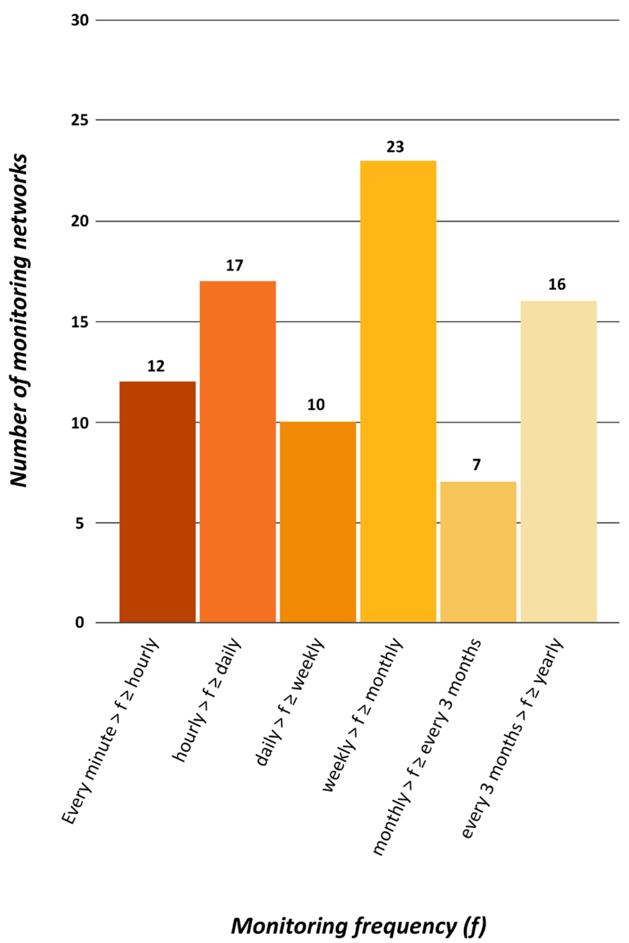


Fig. 7 – Monitoring frequency

Automatic monitoring is used in at least 42 countries, from which in 28 in combination with manual monitoring. The monitoring method was not reported for in 30 countries. However, in some cases it can be assumed from information about frequency of observation: for instance, if monitoring is done less than every 3 months to yearly, it is likely that it is done manually (e.g. Algeria, Colombia, Malaysia, Tunisia, Uruguay) while if measurements are taken hourly, it is clear that an automatic network is in place (e.g. New Zealand).

In every case when (only) manual data collection was reported, the frequency of observation was given as well, ranging from less than daily to yearly. In several cases the frequency of observation was not provided, but it can be derived from the method used to collect data. When there is a water level logger installed in the well, it can be expected that data are taken several times a day, or daily (e.g. Australia, Myanmar, Paraguay, Somalia, Switzerland).

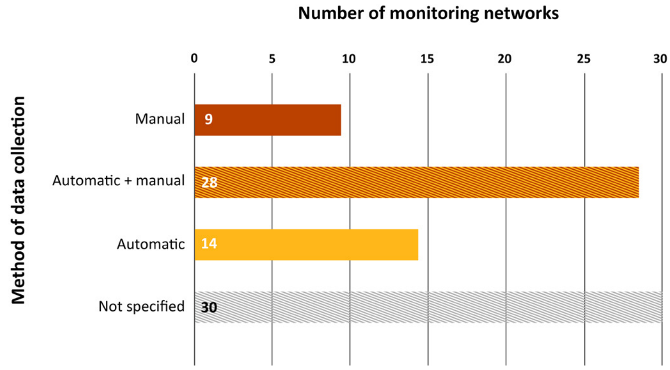


Fig. 8 – Methods of data collection

In some cases where a wide range of frequencies is reported it can be assumed that both manual and automatic methods are used (e.g. Chile, France, Serbia).

Information on the monitoring method and frequency of observation was not found for 8 countries from which no feedback was received either.[5] Although feedback was received from Eswatini, Ghana, Greece and Hungary, this piece of information was not included. Hopefully, it will be added in a second edition of this overview.

IV. PROCESSING

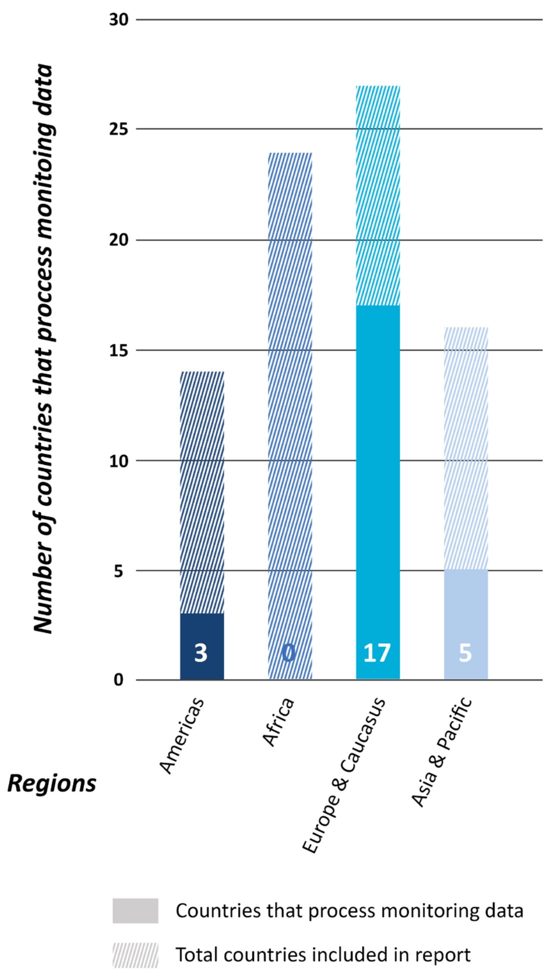


Fig. 9 – Number of countries that proccess monitoring data per region

[5] *Cambodia, Guinea-Bissau, Indonesia, Luxembourg Mexico, Nepal, Uganda and Venezuela.*

At least 33 countries provide reports on outcomes of groundwater monitoring, and 41 produce groundwater maps (groundwater level interpolation maps, trend maps, etc. In many cases, maps are included in the reports, as it is the case with the Hydrographic Yearbook of Austria (page 64).

Although several countries reported producing maps and/or reports, it is not clear how to access them. In total, 25 countries (31%) reported processing of groundwater level data (countries which reported "time series analysis" but without describing methods used and results obtained were not considered in this statistics).

COUNTRY	PRODUCT	MORE DETAILS
Australia	1) Groundwater level status map; and 2) Groundwater level trend maps.	1) 30th and 70th percentile of 20 years record to classify current level as above average, average and above average; and 2) Trends for 5, 10 and 20 years as rising, stable and declining
Austria	1) Deviation of average groundwater level; 2) Analysis of seasonal change; and 3) Changes in groundwater volume.	1) Values compared to ±33% and ±100 of historical record; 2) Daily groundwater level change in wells is compared with long term statistics; and 3) Estimation of volume of water recharge of discharge from a catchment area considering average porosity.
Belgium	1) Indicators for the relative and absolute status of groundwater; 2) Increase or decrease of water table; and 3) prediction of groundwater levels.	1) Comparison of simulated level with 10, 30, 70, 90 percentile of historical data; 2) Comparison of current level with previous month; and 3) Three scenarios are modelled to predict future groundwater levels for next month: wet, normal and dry.
Canada	Statistics	Standard deviation, minimum, maximum, mean per well.
Chile	Statistics	Statistical reports
Czech Republic	Map for shallow boreholes and springs, and deep boreholes	Cumulative Frequency Curve (CFC) is used to compare monthly levels with historical data, considering non-exceedance probabilities of 5%, 15%, 25%, and 75% to classifies levels from below to above normal.
Finland	Short-term groundwater table forecasts	Map classifies groundwater levels as above the highest value, above the annual average, above average, below average, below the annual average and below the lowest value.
France	Standardised Piezometric Indicator (IPS) applied to groundwater level maps	IPS ranges from -3 and +3 and seven classes are defined based on IPS values from very low to very high.
Germany	Low Water Information Service to prepare against dry periods on an early stage	10, 25, 75 and percentile are used to classified levels as no low water, low, very low and new lowest value.
Italy	Piezometric reference level	Range of fluctuation between the 1st and 3rd quartiles of monthly long-term values (9-15 years)
India	Groundwater level fluctuation maps	Comparison of current water level with previous year, and decadal change
Ireland	Groundwater level maps	Map shows how groundwater levels are relative to the seasonal averages and 95%iles.
Lithuania	Groundwater level maps	Groundwater level relative to mean long-term depth, categorised as close to average, above average and below average.
Netherlands	1) Contour lines; and 2) Groundwater Dynamics.	1) Contour lines are calculated based on levels from three different databases; and 2) A transfer function-noise model with precipitation and evaporation as independent variables is used to calculate the influence of annual seasonal patterns on groundwater levels.
New Zealand	Statistics	Mean, minimum and maximum levels.
Norway	Groundwater level graphs	Groundwater levels are analysed through median, 25% and 75% percentile and presented as time series graphs.
Poland	Quarterly Groundwater Information Bulletin	Statistics

Table 1 – Groundwater level data processing methods

COUNTRY	PRODUCT	MORE DETAILS
Portugal	Groundwater quantity report	The average groundwater level and the 20%-percentile are de¬-termined for historical data. Current month values are compared with previous statistics and divided in three classes: above aver-age, between average and 20% percentile, and 20% percentile.
Serbia	Groundwater level graphs	Statistics
Sweden	Groundwater level maps	Reference statistics are used to interpret groundwater levels related to seasonal patterns or historic variability. Seasonal reference classify levels from much below normal to much above normal, and overall variability from extremely low to extremely high.
Switzerland	Groundwater level maps	10 and 90% percentile are used to classify levels as low, normal and high in relation with historical data.
Thailand	Groundwater level maps	Statistics
United Kingdom	Groundwater level maps	Records in a given month are ranked. Map displays the rank of current month with respect to all historical measurements on that month.
United States	1) Active groundwater level network, climate response network, real-time groundwater level network, below normal groundwater levels network; and 2) National Aquifer Composite Hydrographs.	1) 10, 25, 75, and 90% percentile are used to classified levels from much below normal to much above normal; and 2) Composite hydrographs use the median water level for the period of interest for each well and then averages all wells for a particular year of month. Results are presented on a hydrograph.
Vietnam	Forecasting tool	Groundwater data are fed to the national monitoring data man-agement system.

Table 1 (continued) – Groundwater level data processing methods

The majority of the countries that process groundwater levels (16) is producing maps categorising groundwater level such as “above/below normal”, “above/below average”, “high/low groundwater level”, etc. These countries are: Australia, Austria, Belgium, Czech Republic, Finland, France, Germany, Italy, Ire-land, Lithuania, Norway, Portugal, Sweden, Switzerland, United Kingdom and United States.

This type of maps is a simple and effective way to inform policy makers and the public about the status of groundwater resourc-es. Long groundwater level records (time series) are usually needed to produce such map (figure 10). The map can include other information as well (e.g. homogenious areas within an aquifer) in order to make further assumptions about spatial distibution of groundwater levels (figure 11).

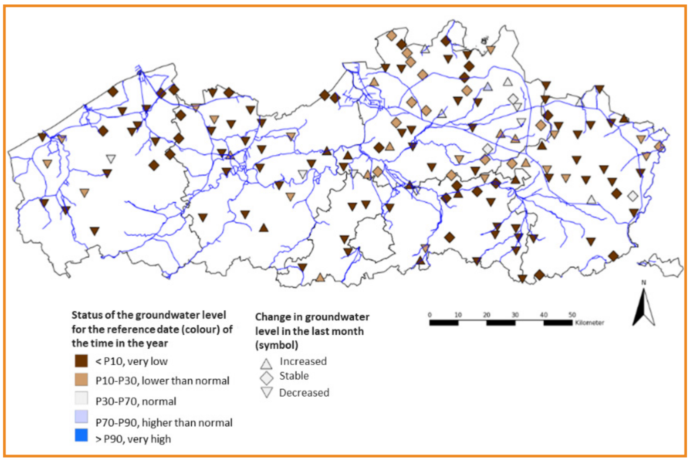


Fig. 10 – Groundwater levels in Flanders (Belgium) in a given month. As most of stations appear either light or dark brown, It is clear that most groundwater levels were lower than normal or very low for this time of the year. (more information on page 67)

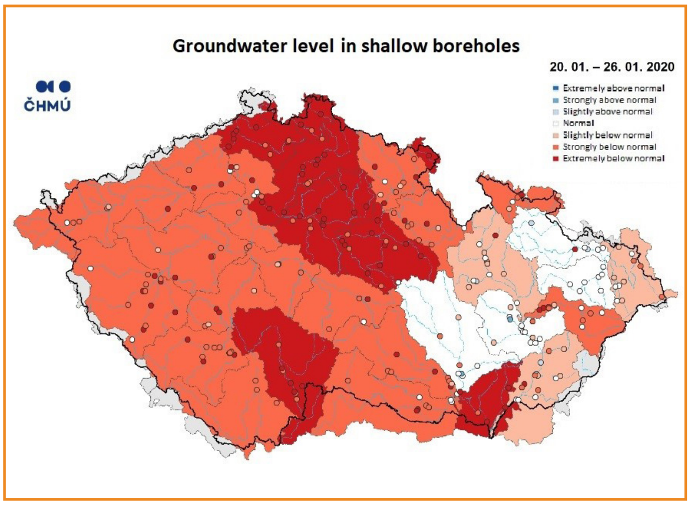


Fig. 11 – Groundwater levels in Czech Republic in January 2020. Groundwater levels ranged from slightly below normal to ex-tremely below normal in most of the country for the considered period (more information in page 72)

A map is not the only way of representing categories of ground-water levels: a good example of this is the Indicator of ground-water levels and spring discharges found in Switzerland (figure 12, next page), which is presented in graph form. Another ex-ample are the National Aquifer Composite Hydrographs pro-duced in the United States (figure 13, next page).

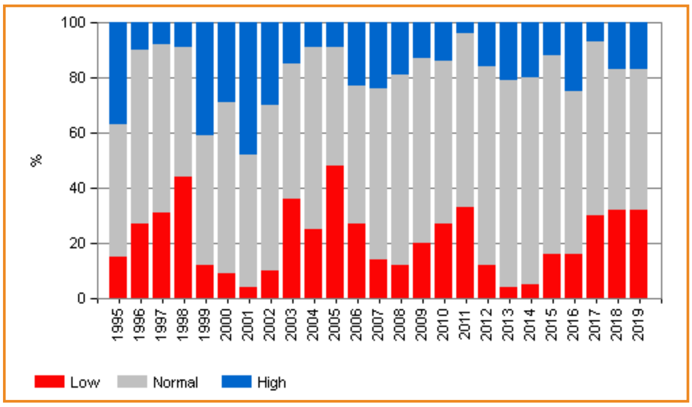


Fig. 12 – Indicator for Groundwater levels and spring discharge rates in Switzerland. The graph shows, for example, that in 2001, 2013 and 2014 only around 5% of the monitoring stations registered low groundwater levels (more information in page 112).

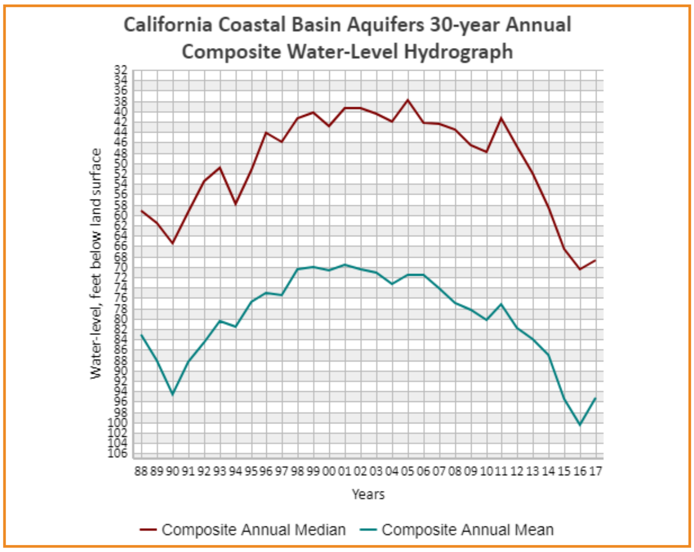


Fig. 13 – Composite hydrograph for the California Coastal Basin Aquifer in the United States showing the change of the mean and median depth of groundwater levels between 1988 to 2017. The graph indicates, among others, that the groundwater levels reached their lowest points in 1990 and 2016 (more information on page 32).

V. AVAILABILITY OF INFORMATION

It was found that 51% of the countries (41) have a web-based GIS data portal (a map portal) to disseminate groundwater information. From these countries, four did not provide a portal address (Estonia, Greece, Korea, Pakistan). Czech Republic and Finland disseminate maps not in a map portal but as static images. Nevertheless, they are included in this analysis due to their quality and updating frequency (monthly and daily, respectively). Table 2 provides the links to groundwater portals for each country.

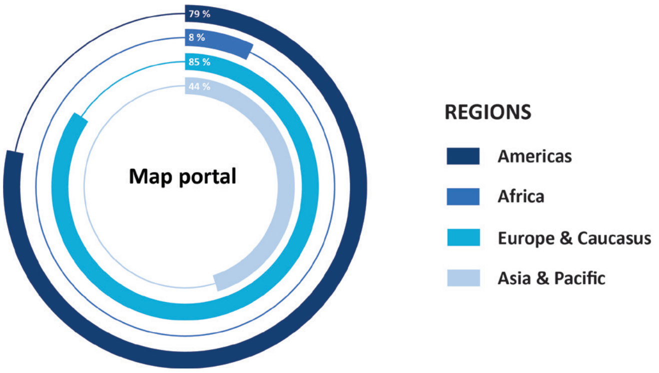


Fig. 14 – Countries with a map portal with groundwater information, per region (in %)

COUNTRY	LINK TO MAP PORTALS
Argentina	http://www.azul.bdh.org.ar/bdh3/leaflet/index.html
Australia	http://www.bom.gov.au/water/groundwater/explorer/map.shtml; and http://www.bom.gov.au/water/groundwater/insight/#/overview/introduction
Austria	https://www.ehyd.gv.at/
Belgium	https://www.dov.vlaanderen.be/portaal/?module=verkenner&bm=9bba534d-0745-46ef-aa95-c31788c2266a; and http://piezo.environnement.wallonie.be/GeneralPages.do?method=displayStationsMap&time=2020-11-13%2016:29:49.621
Bolivia	http://ide.sergeomin.gob.bo/wsihibo/
Brazil	http://rimasweb.cprm.gov.br/layout/visualizar_mapa.php
Canada	https://gin.gw-info.net/service/api_ngwds:gin2/en/wmc/standard.html
Chile	https://snia.mop.gob.cl/observatorio/
Colombia	http://sig.anla.gov.co:8083/
Costa Rica	http://mapas.da.go.cr/mapnew.php

Table 2 – Links to national web-based GIS data portal/updated groundwater maps

COUNTRY	LINK TO MAP PORTALS
Czech Republic	http://portal.chmi.cz/aktualni-situace/hydrologicka-situace/stav-podzemnich-vod
Denmark	https://data.geus.dk/geusmap/#baslay=baseMapDa&optlay=&ex-tent=14783.991319444496,5981402.521701388,1214281.7690972222,6505245.691840276
El Salvador	http://srt.snet.gob.sv/sihi/public/app/1/pozosmonitoreo
Finland	http://wwwi2.ymparisto.fi/i2/90/gvyy2/tanaan_en.html
France	https://ades.eaufrance.fr/GeoSIE
Germany	https://www.nid.bayern.de/grundwasser
Guinea Bissau	https://portal.mwater.co/#/dashboards/9c20165c8763489b85baf898bda1dca3?share=2bb-0050028d540298277e50208717545
India	https://indiawris.gov.in/wris/#/groundWater
Ireland	http://www.epa.ie/hydronet/#Groundwater
Latvia	https://www.meteo.lv/pazemes-udens-staciju-karte/?&nid=474
Lithuania	https://www.lgt.lt/epaslaugos/index.xhtml
Luxembourg	https://map.geoportail.lu/theme/main?version=3&zoom=8&X=667917&Y=6394482&lang=fr&rota-tion=0&layers=&opacities=&bgLayer=basemap_2015_global
Mexico	https://sigagis.conagua.gob.mx/rp/
Netherlands	https://www.grondwatertools.nl/grondwatertools-viewer
New Zealand	https://www.tasman.govt.nz/my-region/environment/environmental-data/groundwater-levels/
Norway	http://www2.nve.no/h/hd/plotreal/GRW/index.html
Peru	http://snirh.ana.gob.pe/visorPozos/
Portugal	https://snirh.apambiente.pt/index.php?idMain=1&idItem=1.4&idSubItem=BOL&massaagua=2039044
Serbia	http://www.hidmet.gov.rs/eng/hidrologija/podzemne/index.php
Somalia	https://fmt.faoso.net/imms/fmt/maps/website/227
Spain	https://sig.mapama.gob.es/redes-seguimiento/
Sweden	https://apps.sgu.se/kartvisare/kartvisare-grundvattenniva.html
Switzerland	https://www.hydrodaten.admin.ch/en/messstationen_grundwasserzustand.html
Thailand	http://tgms.dgr.go.th/#/home
United Kingdom	https://eip.ceh.ac.uk/hydrology/water-resources/
United States	https://cida.usgs.gov/ngwmn/index.jsp
Vietnam	http://123.16.176.41/lawis/public/

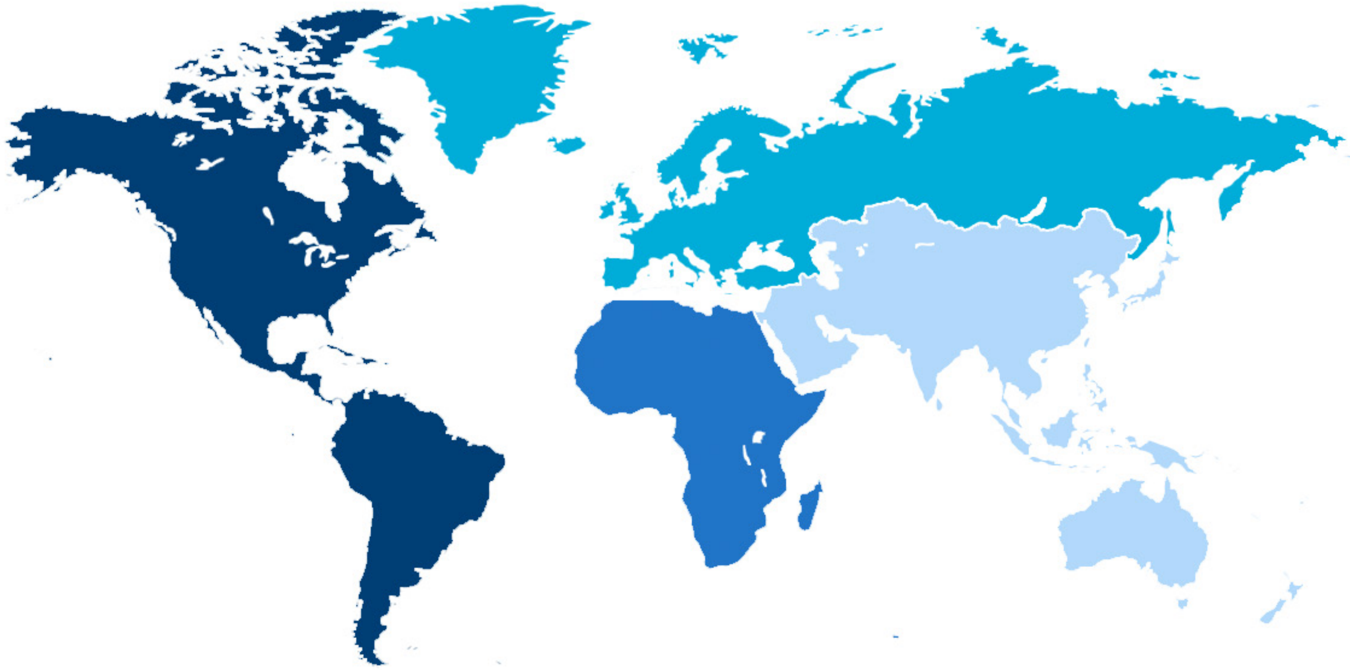
Table 2 (continued) – Links to national web-based GIS data portal/updated groundwater maps

Concluding remarks

The first overview (or rather an inventory) was made more than 15 years ago and information collected then was quite limited. If is therefore difficult to say whether the groundwater monitoring networks in meantime expanded worldwide or perhaps reduced in their density. Nevertheless, the frequency of observations increased, primarily due to development of technically advanced and affordable loggers. Further, accessibility to information substantially increased also thanks to expansion of web-based portals and eagerness of responsible organisations to provide monitoring services and justify (usually public) investments in groundwater monitoring.

This overview is a first edition, to be updated by countries as they progress in monitoring, processing and dissemination of information on state of groundwater resources. Larger involvement of regional organisations would be certainly beneficial for the further development of this overview. The analysis shown in this introduction is very preliminary: hopefully this overview will encourage a discussion on various aspects of monitoring and in particular on (spatial and temporal) processing and interpretation of monitoring data. IGRAC will be happy to facilitate a discussion and promote the outcomes.

COUNTRY PROFILES



THE AMERICAS

Argentina

Capital city: Buenos Aires
Inhabitants: 44 Million

INSTITUTIONAL SETTING AND PURPOSE

Water resources in Argentina are owned by the Provinces, but the National Hydrological Network (RHN), belonging to the Federal State, has its own hydrometric, surface water quality, limnometric and meteorological stations.

The main objective of the RHN is to provide data on water resources, status and trends in the medium- and long-term for the planning of water policies at the federal level, and to contribute to the integrated water resources management at the scale of transboundary basins.

RHN is in the process of installing its first piezometric stations, prioritizing transboundary basins. In addition, the RHN continues its tasks of incorporating and integrating into the information system the provincial stations of basin organizations (ACUMAR, COREBE, AIC, COIRCO, CIC-Plata, etc.), of research institutes (INA, INTA, IHLLA) and municipal early alert and other independent networks (e.g. Red Mate). At the moment there is no national groundwater monitoring network, but some local networks exist.

CHARACTERISTICS OF THE NETWORK

The monitoring networks of the basin and municipal organizations (early alert) usually collect data on groundwater quantity (levels) and quality. The RHN, for its future hydrogeological stations, plans to make measurements of quantity (level) and quality (conductivity, pH and temperature) with seasonal regularity.

There are manual, automatic and/or telemetric stations depending on the objective of the monitoring.

PROCESSING AND DISSEMINATION

Data from the basin organizations are available on their web pages. By national law, information produced with state funds at any level is public and must be accessible to all citizens, as long as it does not compromise the national security.

The Integrated Hydrological Database (BDH) portal contains time series of all the stations that it installs, maintains and operates. At the moment groundwater monitoring stations are not included in the website.

Dat.ar is the unofficial repository of open public data of Argentina; it contains information on about 5500 SIFAS (Federal Groundwater Information System) wells (update until 2015). Data from these wells can be downloaded, including name, type, coordinates and owner.

The georeferenced overview of wells used to be available through the SIFAS portal of the Ministry of the Interior, updated until 2015. At present, it is not possible to access the website.

EXAMPLE OF LOCAL NETWORK: BDH-AZUL

BDH-Azul is the Hydrological Database of the Azul basin, which depends on the Institute of Plains Hydrology “Dr Eduardo Jorge Usunoff” (IHLLA). The IHLLA has a wide monitoring network of meteorological parameters, surface water and groundwater throughout the basin. Some of them are also linked to the flood early warning system of Azul. This information is available for users since 2002 on a hydrological information management web portal.

On the BDH-Azul web portal (figure below) the georeferenced position of 149 wells is visualised and related data and metadata can be downloaded, such as coordinates of the wells and groundwater level time-series. Around half of these wells have been flagged as “exploitation” type, and the other half as “other”. The frequency of data collection is irregular, ranging from approximately 4 times a year to twice a month.

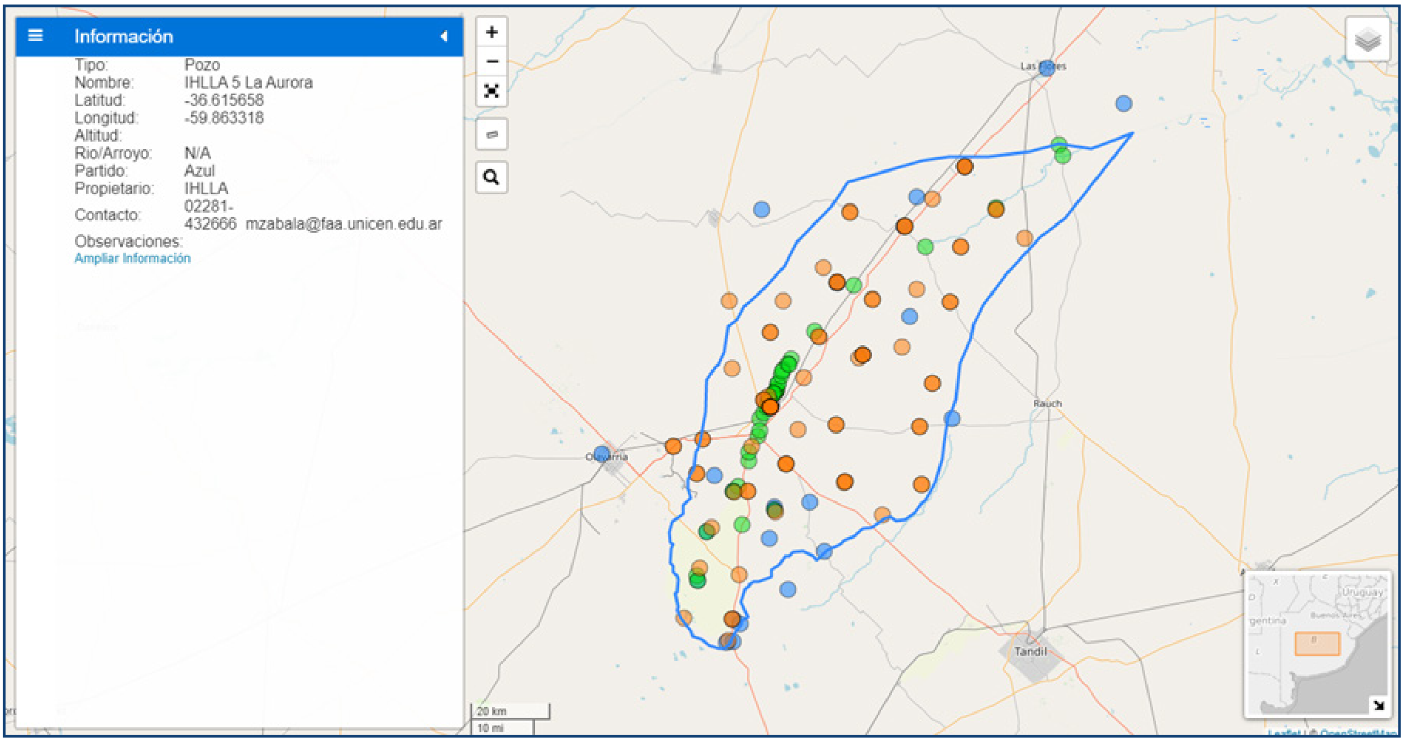


Fig. 15 – BDH-Azul web portal

Fig. 16 – Dry landscape of Cordoba, Argentina, by: Richard

Sources

- **BDH-Azul web portal** - http://www.azul.bdh.org.ar;
- **CeReGAS (Regional Centre for Groundwater Management in Latin America and the Caribbean)** - personal communication, 2019;
- **Feedback from IHLLA** - received on 28 February 2020;
- **Feedback from National Secretariat of Infrastructure and Water Policy - SIPH (answer to form)** - coordinated by CeReGAS and received in 2019;
- **Integrated Hydrological Database of Argentina (BHD)** - http://bdhi.hidricosargentina.gob.ar;
- **National Water Institute (INA)** - email exchange, 2020;
- **SIFAS portal** - http://sisag.mininterior.gob.ar/SIFAS/ (no longer available); and
- **Unofficial repository of open public data of Argentina, Dat.ar** - http://datar.noip.me/dataset/pozos-sifas.

Bolivia

Capital city: Sucre
Inhabitants: 11 Million

INSTITUTIONAL SETTING AND PURPOSE

The Ministry of Environment and Water (MMAyA) is in charge of water resources management in Bolivia and has three underministries being responsible for different fields. The Underministry of Water Resources and Irrigation contributes to the development and execution of plans, policies in Integrated Management of Watersheds and Irrigation, and designs strategies for the conservation and use of surface and groundwater. For instance, this underministry participates and coordinates the management of the Yrenda-Toba Tarijeño aquifer system within the framework of the Inter-American Committee of the Plata Basin with the Binational Commission together with Argentina, Paraguay and UVSMA/OAS and ISARM Americas.

There is no national groundwater monitoring programme in Bolivia but several local groundwater monitoring networks in place. For example, the groundwater monitoring network in the Katari River Basin and in the Yacuiba municipality.

CHARACTERISTICS OF THE NETWORK

1. Groundwater monitoring network in the Katari River basin

MMAyA is in charge of the Master Plan for the Katari River basin since 2010. Two aquifers are located in this area: the Purapurani and the Viacha aquifers (figure 17). They are being monitored since 2016 under the Purapurani and Viacha Aquifers Preliminary Management Plan (2016) with the objective to evaluate the spatial and temporal variation of the aquifer regime during the rainy and dry seasons and to assess the groundwater quality.

The monitoring of groundwater levels is carried out monthly and manually in 30 locations. Measurements are mostly carried out manually, but some wells are equipped with automatic sensors.

The data are used for calibration of the numerical flow model developed for this aquifer.

Data processing is done via statistical analysis and spatial interpolations.

2. Groundwater monitoring network from the Drinking Water and Sanitary Sewer Services Providers

According to the Bolivian Standard 512 (NB 512) on drinking water the Drinking Water and Sanitary Sewer Services Providers (EPSAs) must take water samples from wells twice a year. The EPSA of the Yacuiba municipality, in the Tarija department, has 28 wells. Measurements of groundwater levels are taken there manually once a month (static and dynamic levels), together with groundwater flow and energy consumption.

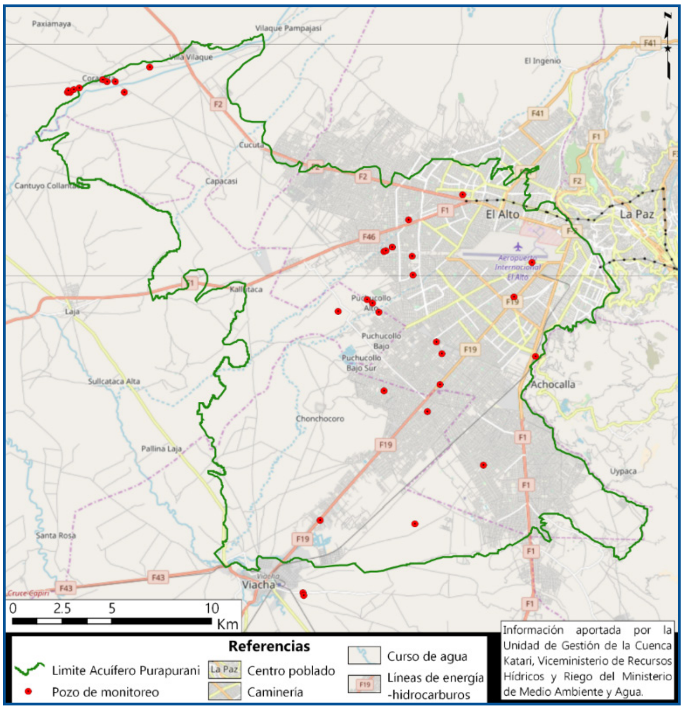


Fig. 17 – Location of monitoring points in the Purapurani Aquifer. Source: Katari Basin Management Unit, Underministry of Water Resources and Irrigation of the Ministry of Environment and Water.

PROCESSING AND DISSEMINATION

Groundwater data collected under the Master Plan for the Katari River basin is accessible only for governmental organisations. Data collected by the EPSA of the Yacuiba municipality are available by request (at the municipality).

Additionally, two country-wide information systems contain metadata of wells and various hydrogeological information: SIHIBO and SIASBO.

The Mining and Geological Service (SERGEOMIN) of Bolivia launched the Hydrogeological Information System of Bolivia (SIHIBO) in 2016 (figure 18). SIHIBO contains information on 3000 water wells drilled by SERGEOMIN for more than 40 years. Among the data included per well are: lithological, geological, geophysical and geochemical data, water analysis and monitoring, as well as other socioeconomic variables.

The Ministry of Environment and Water hosts the Bolivian Groundwater Information System (SIASBO), a web platform where locations of wells (updated until 2016) can be visualised along with downloadable metadata.

Neither SIHIBO or SIASBO store groundwater level data so far.

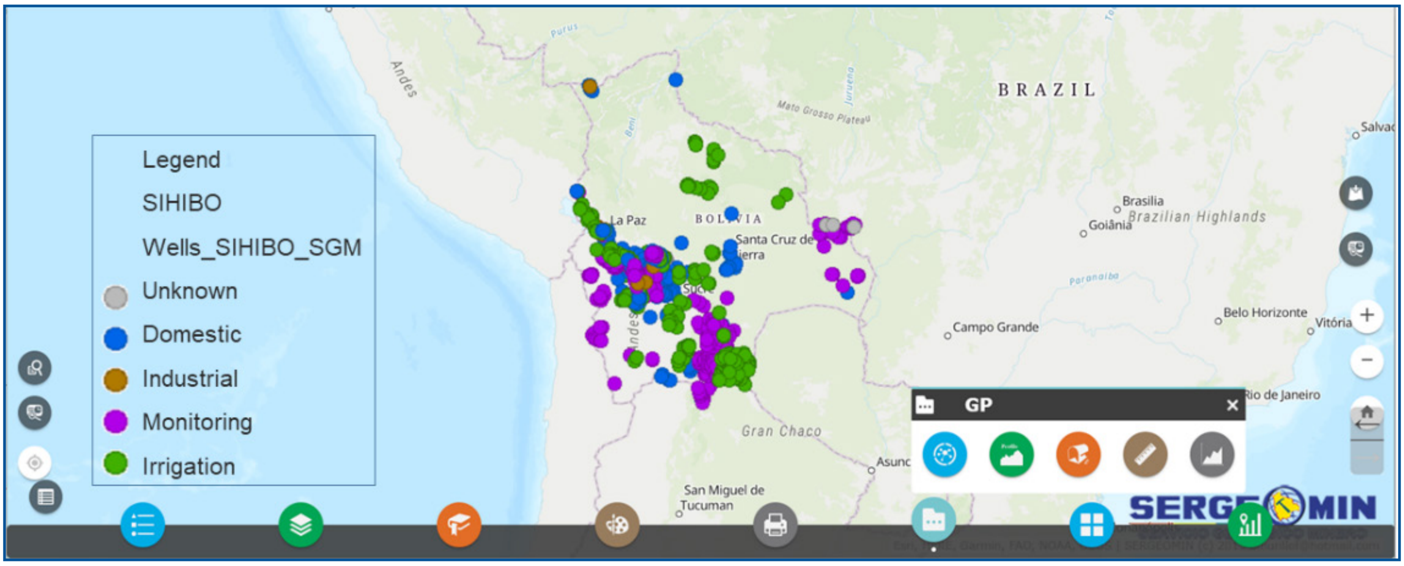


Fig. 18 – SIHIBO

Sources

- **Feedback from German Cooperation PERIAGUA-GIZ (answer to form)** - received in 2018;
- **Feedback from MMAyA (answer to form)** - coordinated by CeReGAS and received in 2019;
- **Vice Ministries -** https://www.mmaya.gob.bo/viceministerios/viceministerio-de-recursos-hidricos-y-riego/atribuciones;
- **SIHIBO -** http://ide.sergeomin.gob.bo/wsihibo;
- **SIASBO -** http://geosirh.riegobolivia.org/layers/geosirh:pozos_siasbo_1; (currently not available) and
- **Ward Quaghebeur, Riley E. Mulhern, Silke Ronsse, Sara Heylen, Hester Blommaert, Sid Potemans, Carla Valdivia Mendizábal, Jhonny Terrazas García, 2009. Arsenic contamination in rainwater harvesting tanks around Lake Poopó in Oruro, Bolivia: An unrecognized health risk -** https://doi.org/10.1016/j.scitotenv.2019.06.126.

Brazil

Capital city: Brasília
Inhabitants: 209 Million

INSTITUTIONAL SETTING AND PURPOSE

The National Water Agency (ANA) is in charge of Planning, Monitoring and Management Support of Water Resources, providing information on water resources to other governmental water managing bodies and entities at the federal and the federal states level. The Agency is legally responsible for implementing the National Water Resources System (SINGREH), which is a combination of legal and administrative mechanisms established by the Water Law (1997). Its aim is to coordinate integrated water resources management and implement the National Policy of Water Resources. However, the Geological Service of Brazil (CPRM or SGB) is the institution that manages the Integrated Groundwater Monitoring Network (RIMAS), the national groundwater network of Brazil.

CPRM is responsible for planning and implementation of monitoring activities; data collection and maintenance of monitoring wells, as well as for data consistency and data dissemination through the national well database. The States are responsible for licensing groundwater use.

Data are collected with the objective of expanding hydrogeological knowledge, developing specific research and supporting the management of water resources.

CHARACTERISTICS OF THE NETWORK

RIMAS is comprised of approximately 400 monitoring wells located throughout the country. The collection of automatically recorded groundwater levels is done three to four times per year.

Selection of locations and equipment for monitoring wells was made by the CPRM and external consultants from universities, environmental agencies, and other organisations. New wells are constantly added to RIMAS to improve the spatial distribution of monitoring. The process for choosing monitoring locations, is done with the criteria on aquifers prioritization, namely:

1. Sedimentary aquifers;
2. Water of socio-economic importance;
3. Use of water for public supply;
4. Aspects of natural vulnerability and risks;
5. Spatial representativeness of the aquifer; and
6. Existence of monitoring wells.

Fig. 19 – Foz do Iguaçu, water falls connected to Paraná river and thereby Guaraní aquifer, by: S. Siepman

PROCESSING AND DISSEMINATION

Data and reports can be visualized and downloaded from the RIMAS web platform. The CPRM is also responsible for the Groundwater Information System (SIAGAS), a national information system created to support groundwater management in the country. The SIAGAS is composed of a monitoring well database and modules for consultation, information extraction and report generation. The database is constantly updated and can be combined with other systems. At this moment, the SIAGAS has a total of 321,621 registered wells.

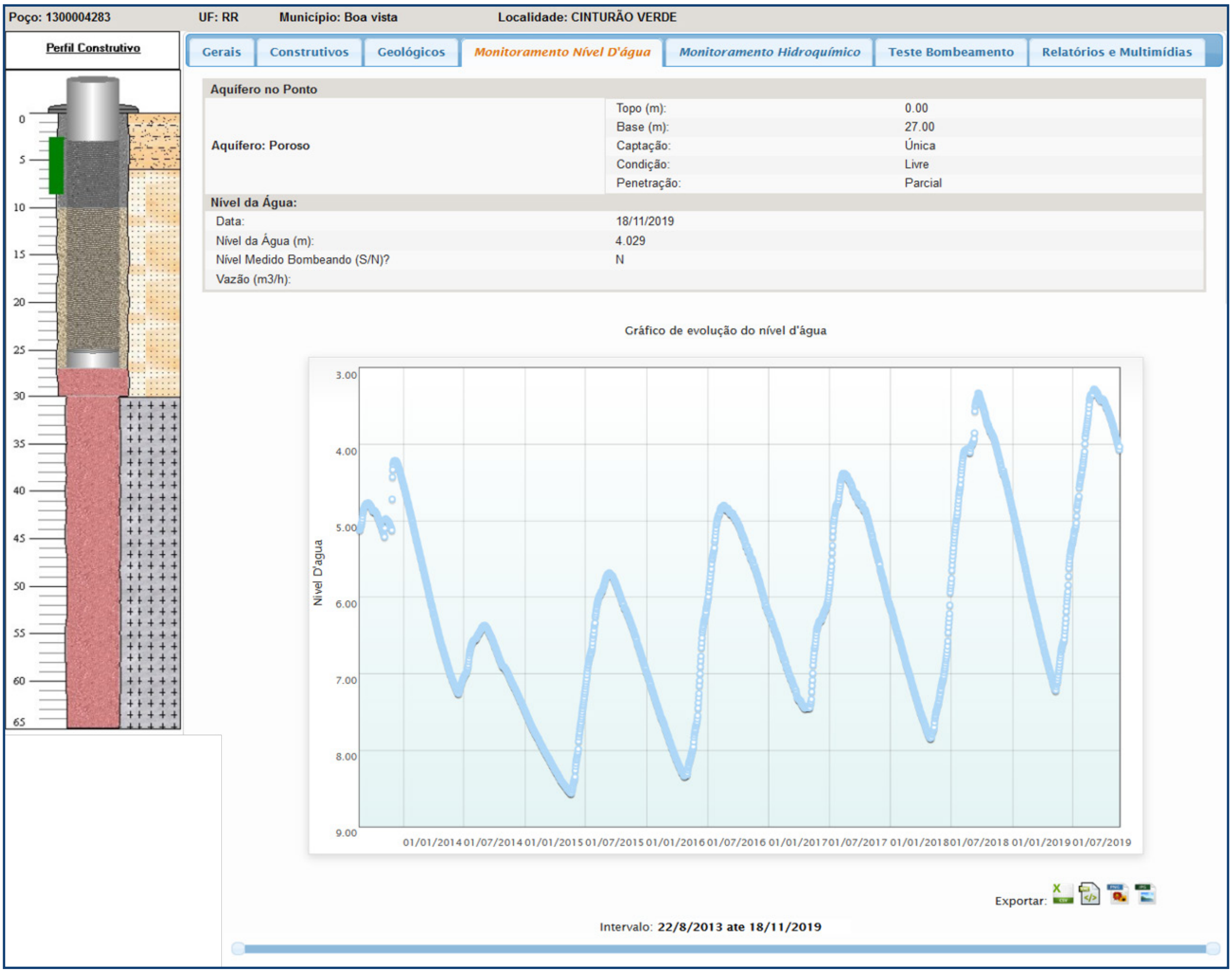


Fig. 20 – Integrated Groundwater Monitoring Network

Sources

- **Integrated Groundwater Monitoring Network (RIMAS)** - http://rimasweb.cprm.gov.br/layout/apresentacao.php;
- **Groundwater Information System (SIAGAS)** - http://siagasweb.cprm.gov.br/layout/apresentacao.php;
- **Agência Nacional De Águas (ANA)** - https://www.ana.gov.br; and
- **Feedback from CPRM** - received of 17-03-2020.

Canada

Capital city: Ottowa
Inhabitants: 37 Million

INSTITUTIONAL SETTING AND PURPOSE

Under the Canadian constitution, responsibility for natural resources is shared by all levels of government, including federal, provincial, territorial, municipal, and indigenous.

Groundwater monitoring is carried out in a decentralized manner. Most Canadian provinces and territories have an active groundwater monitoring network, or “observation well network”, that integrates local and municipal networks. The objective of these networks is to monitor seasonal and annual long-term fluctuations. Many wells are located in important aquifers where stresses caused by anthropogenic groundwater extraction and/or climatic variations are monitored. This provides valuable insight on the magnitude of groundwater recharge and aquifer depletion.

The monitoring networks also play an important role in assessing aquifer sustainability, especially when limited data on actual groundwater use are available in parts of Canada.

CHARACTERISTICS OF THE NETWORK

The number of wells in provincial and territorial monitoring networks ranges widely, from tens to many hundreds. The Groundwater Information Network (GIN) then integrates much of this data into a single national network.

PROCESSING AND DISSEMINATION

GIN is a data network and web portal dedicated to the improvement of knowledge about groundwater systems by increasing access to groundwater information. Water well and water monitoring data, to name a few, are collected from provincial and territorial collaborators such as British Columbia, Alberta, Saskatchewan, Manitoba, Ontario, Québec, Nova Scotia, Newfoundland and Labrador, and Yukon. The GIN web portal allows users to view, download and query groundwater information online (figure 21). Several types of groundwater information can be requested in formats such as GWML (Groundwater Markup Language), Excel, Google Earth, ESRI Geodatabase, ESRI shapefile and PDF.

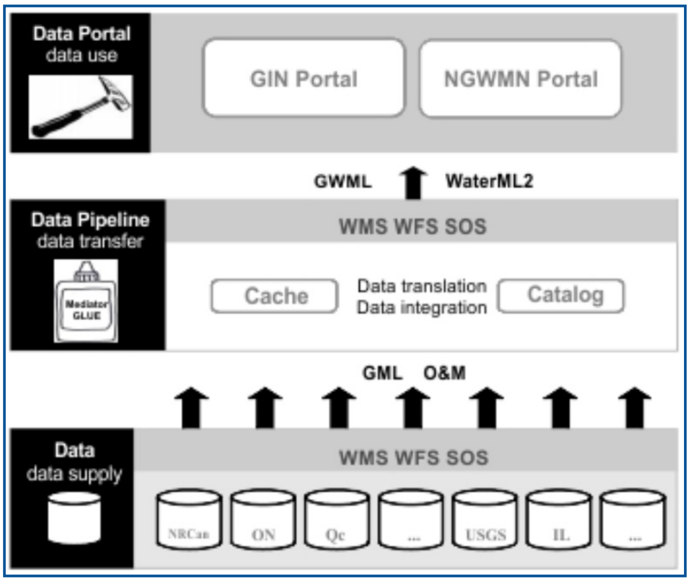


Fig. 21 – GIN Portal pre-processing

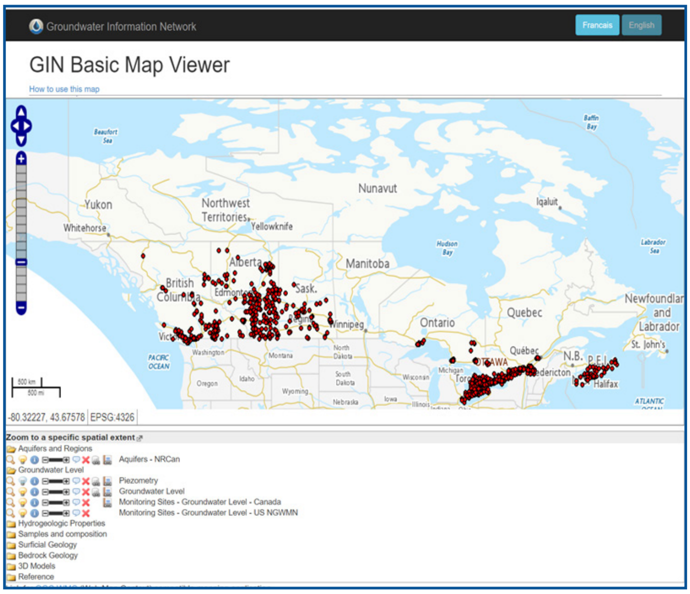


Fig. 22 – Groundwater monitoring sites of Canada. Source: GIN

Monthly values of groundwater levels, related statistics, location and borehole characteristics are presented in the portal for each monitoring station (figure 23), where available.

NRCan (Natural Resources Canada) also worked closely with the U.S. Geological Survey (USGS) and the international community to develop the WaterML2 data standards and best practices, including GroundwaterWML2 (https://www.ogc.org/standards/waterml; Brodaric et al. 2018). Combined with the adoption of other data access standards and technologies from the Open Geospatial Consortium, this has resulted in the ability to seamlessly retrieve groundwater level data from either GIN or the National Groundwater Monitoring Network (NGWMN) of the United States (Brodaric et al. 2016).

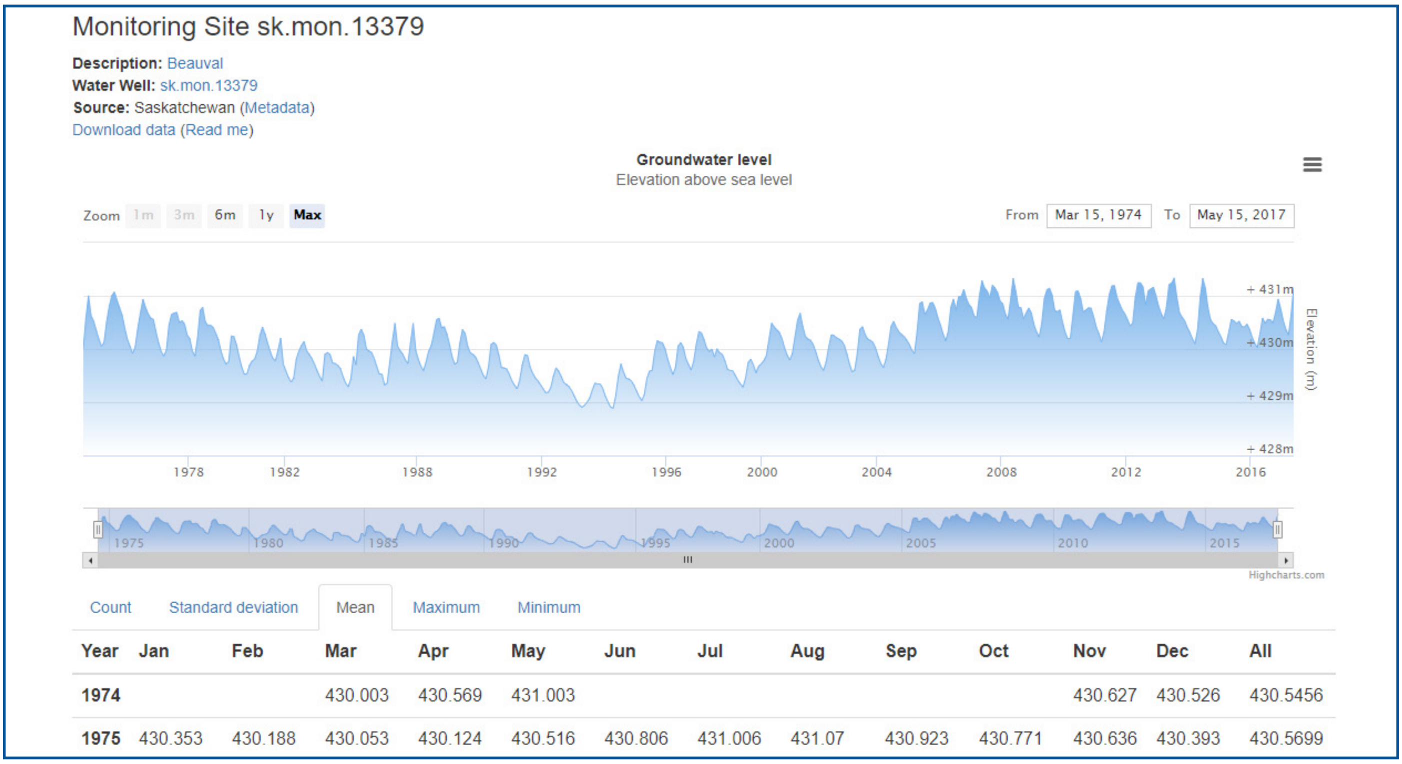


Fig. 23 – Example of monitoring well from Monitoring Sites of Canada (GIN)

Sources

- **Brodaric, B., Booth, N.L., Boisvert, E., Lucido, J. Groundwater Data Interoperability. Journal of Hydroinformatics, 18(2):198-225** - https://doi.org/10.2166/hydro.2015.242;
- **Brodaric, B., Boisvert, E., Chery. L., Dahlhaus, P., Grellet, S., Kmoch, A., Letourneau, F., Lucido, J., Simons, B., Wagner, B. Enabling Global Exchange of Groundwater Data: GroundWaterML2 (GWML2). Hydrogeology Journal, 26(3):733-741** - https://doi.org/10.1007/s10040-018-1747-9;
- **Feedback from NRCan** - received on 06-07-2020;
- **GGMN People Network** - email exchange;
- **Groundwater Information Network (2020)** - http://gw-info.net. Accessed 28 January 2020; and
- **Rivera A (ed) (2014) Canada's groundwater resources. Geological Survey of Canada. Fitzhenry & Whiteside, Markham, ON** - ISBN: 978-1-55455-292-4 (HC).

Chile

Capital city: Santiago
Inhabitants: 18 Million

INSTITUTIONAL SETTING AND PURPOSE

The General Directorate of Water (DGA) is the state agency responsible for researching, monitoring and planning the development of the National Water Resources. It provides high-quality information about the National Water Resources in a systematic way, and disseminates the information generated by its own Hydrometric and Public Water Cadastre's Networks. The management of groundwater level and groundwater quality monitoring are some of the functions of DGA.

PROCESSING AND DISSEMINATION

Interactive maps of the national aquifers are available in the DGA Georeferenced Observatory build on an ArcGIS online platform, figure 24. The Groundwater Hydrometric Network is also shown in here, including an associated groundwater quality index per well, figure 25.

The National Water Information System (SNIA) managed by the DGA is aimed to improve the management of institutional information. Through this portal, users have access to several official statistical reports of hydrometeorological variables and water quality, including data on (static) groundwater levels from the national network.

The portal allows downloading reports of up to 10 stations simultaneously, defining a search period of up to 40 years for annual data, 10 years for monthly data, and 4 years for daily data. Reports are generated in Excel format.

Law No. 20,285 on transparency and access to public information allows to formally request information and data, which is relevant in the case of variables that are not available on the web platform, or when the complete data set of a certain variable is needed. This must be done through the Integral System of Information and Citizen Attention (SIAC) Platform.

Fig 24 – Aquifers of Chile

Fig. 25 – Web platform of the Hydrometric Network, coloured dots show the quality of the monitoring wells

Sources

- **Bibliographic Catalogue, DGA** - https://dga.mop.gob.cl/estudiospublicaciones/Paginas/default.aspx;
- **Feedback from DGA** - received on 04-02-2020;
- **General Directorate of Water (DGA), Georeferenced Observatory** - http://snia.dga.cl/observatorio;
- **Groundwater monitoring data, DGA** - http://snia.dga.cl/BNAConsultas/reportes;
- **Official Hydrometeorological and Water Quality Information Online, DGA** - http://snia.dga.cl/BNAConsultas; and
- **Water Scenarios 2030: Water deficit indicator in Groundwater in Chile, May 2017** - https://www.escenarioshidricos.cl/wp-content/uploads/2018/12/Indicador-de-D%C3%A9ficit-H%C3%ADdrico-en-Aguas-Subterr%C3%A1neas.pdf.

Colombia

Capital city: Bogotá
Inhabitants: 50 Million

INSTITUTIONAL SETTING AND PURPOSE

The Institute of Hydrology, Meteorology and Environmental Studies (IDEAM), as an institution under the Ministry of Environment and Sustainable Development (MADS) and as a member of the National Environmental System (SINA), is responsible for generating information and knowledge about the state of the country's renewable natural resources. As a national research institute, it plays a fundamental role in the design of policies for the protection and improvement of the environment.

In recent years, IDEAM has worked hand in hand with MADS, the Regional Autonomous Corporations (CARs), and other national institutions in the development of strategies that contribute to the assessment and management of groundwater in Colombia. As a result, the National Groundwater Programme (PNASUB) was formulated. This programme seeks to generate instruments and tools to i) expand knowledge and hydrogeological research of aquifer systems of national and regional importance, ii) allow continuous strengthening of technical, operational and financial capacities of the institutions in charge of managing the groundwater resource, and iii) allow to have validated information and groundwater indicators available through an information system.

Among the expected results of PNASUB, the National Basic Groundwater Network (or reference network) was implemented in 2013, with the objective of collecting information on the natural system and long-term trends of groundwater (in terms of quantity and quality), as well as trends resulting from changes in land use and climatic variation in prioritized national aquifer systems. The network is linked to the CAR's regional monitoring programs.

CHARACTERISTICS OF THE NETWORK

The network monitors prioritized aquifers for which there is an acceptable level of hydrogeological knowledge. The CARs are in charge of monitoring the points chosen for the national network. Monitoring is carried out twice a year for groundwater quantity, characterizing the rainy and dry season, while groundwater quality is monitored once a year. Variables to be monitored are piezometric levels, total hardness, pH, temperature, electrical conductivity, total dissolved solids, dissolved oxygen, redox potential, alkalinity and major ions (Calcium, Sodium, Potassium, Chloride, Sulphate, Nitrate, Bicarbonate, Magnesium and Ammonia).

In total there are 114 monitoring stations in the aquifer systems of the Media Guajira, San Andrés, Valle del Cauca, Glacis del Quindío, Villavicencio - Granada - Puerto López, Golfo de Morrosquillo, Morroa, La Mojana, Cesar, Golfo de Urabá and Valle de Aburrá.

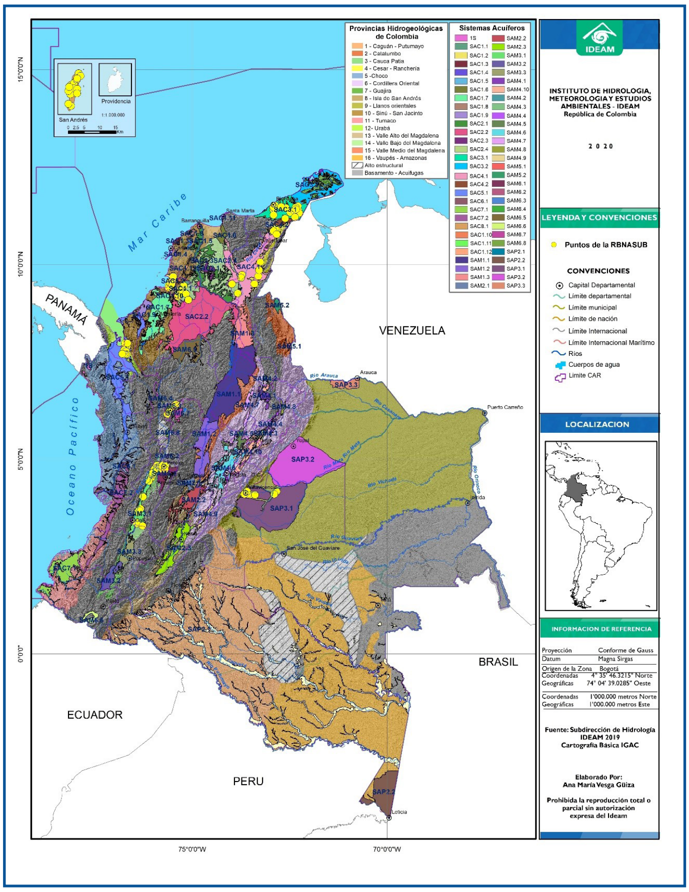


Fig. 26 – Location of the monitoring points that are part of the National Groundwater Network

Fig. 27 – Monitoring of well Gi_GEO_0041, located in Girardota municipality, Antioquia. AMVA

Fig. 28 – Monitoring of well in Hacienda Suarez, located in La Paz municipality, Cesar- CORPOCESAR

Fig. 29 – Monitoring of well Aremasain, located in Manaure municipality- Guajira - CORPOGUAJIRA.

PROCESSING AND DISSEMINATION

Data collected must be uploaded to the Water Resources Information System (SIRH), which systematizes and articulates the information related to water generated by the IDEAM and the Environmental Authorities.

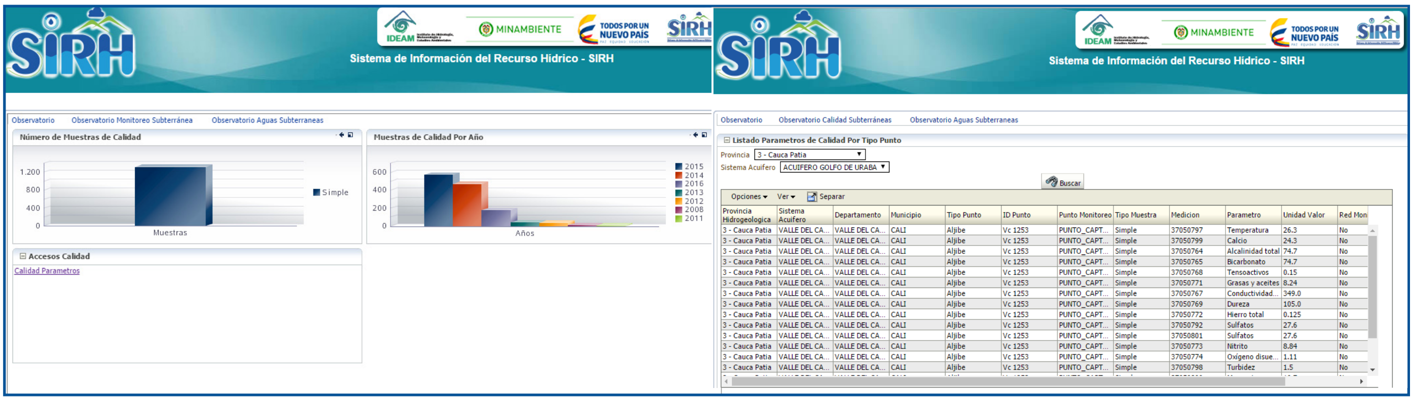


Fig. 30 – View of groundwater information in SIRH

At the moment, users cannot view or download data. However, users can request data to the office of attention to citizens, which delivers it in the required format.

Currently, functionalities of the SIRH regarding reporting, spatialization and web service are being strengthened, which will allow viewing and downloading all information available from the National Groundwater Network. Below it is a proposal of what it is expected to have in the new network Geovisor.

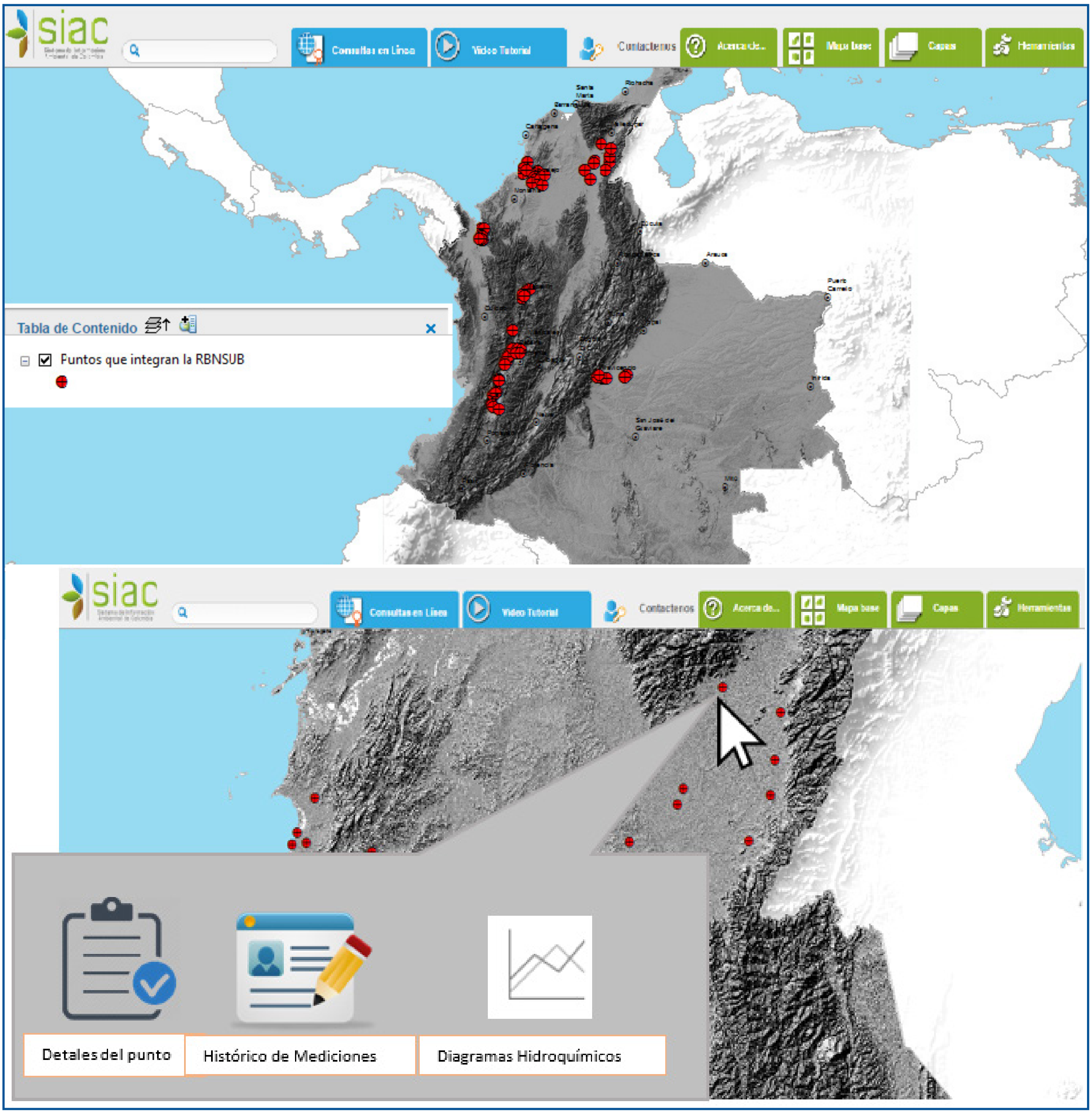


Fig. 31 - Geovisor proposal with information from the National Basic Groundwater Network

Sources

- **IDEAM, Sub directorate of Hydrology (no year). National Basic Network for Groundwater Monitoring in Spanish. Available in -** http://capacitacion.sirh.ideam.gov.co/homeSIRH/HOME/RBSUB/RBASUB.pdf;
- **Feedback from IDEAM** - received on 20-05-2020;
- **Feedback from IDEAM (answer to form)** - received in 2019;
- **SIAC Geographic Viewer -** http://sig.anla.gov.co:8083/;
- **Ministry of the Environment and Sustainable Development, Directorate for the Integrated Management of Water Resources, 2014. National Groundwater Program (PNASUB), in Spanish. Available in** - http://www.minambiente.gov.co/index.php/gestion-integral-del-recurso-hidrico/planificacion-de-cuencas-hidrograficas/acuiferos/programa-nacional-de-aguas-subterraneas; and
- **Colombia's Environmental Information System** - http://www.siac.gov.co/monitoreo.

Costa Rica

Capital city: San José
Inhabitants: 5 Million

INSTITUTIONAL SETTING AND PURPOSE

The Water Directorate (DA) under the Ministry of Environment and Energy (MINAE) of Costa Rica, together with the Costa Rican Institute of Aqueducts and Sewers (AyA) and the National Groundwater, Irrigation and Drainage Service (SENARA) operates several quantitative networks of manual groundwater monitoring and coordinates one automatic network:

1. Automated registration of data via telemetric transmission (Real Time Groundwater Monitoring System, SIMASTIR), and semi-automated transmission (alliance with the Public Utility Company of Heredia, ESPH)
2. Manual monitoring with monthly frequency.

The main objective of these networks is to provide data on the state of groundwater and its long-term trends, and technical information for the proper planning of national policies by regulatory agencies. The data generated is also used to analyse the dynamics of aquifers in the face of climatic variations.

With these monitoring records, representatives of the Institutional Technical Committee (CTI) of Aquifer Management (conformed by Executive Decree 38449-MINE_MAG, DA (as coordinator), AyA and SENARA) proceed to analyse and interpret variations in groundwater levels. Results are made public either by presentation in communities and/or at the National Information System for Integrated Water Resource Management (SINIGHIR) online platform.

CHARACTERISTICS OF THE NETWORK

SIMASTIR (Figure 32) is a national coverage project initiated in 2016 in the province of Guanacaste and extended to the provinces of Heredia and Alajuela by the end of 2020. Monitoring wells record hourly groundwater levels, temperature, and electrical conductivity (in some locations). In the case of automatic transmission, the recorded data is transmitted every 12 hours by cellular signal to the operations centre located at DA offices, where the data is stored and added to the historical records. In the case of semi-automatic transmission, the data is sent monthly by ESPH staff to DA, by email.

The current distribution of the SIMASTIR network by province is as follows:

- **Guanacaste:** 44 groundwater monitoring sites distributed in the following aquifers: right margin Sardinal-Tempisque, Nimboyores, Huacas-Tamarindo, Nicoya, Caimital, Cóbano - Montezuma, Playa Panamá, Coco, Brasilito, Potrero.
- **Alajuela:** 10 groundwater monitoring sites in Aguas Zarcas and Pital aquifers.
- **Heredia**: 21 groundwater monitoring sites in Barba and Colima Superior aquifers. The equipment and maintenance of these monitoring sites is under the responsibility of ESPH, which voluntarily shares the information recorded with SIMASTIR.

The manual network monitors groundwater levels monthly in 300 wells strategically distributed over 10 aquifers located mainly in Guanacaste and the Central Pacific area.

Fig. 32 – Images from the SIMASTIR project

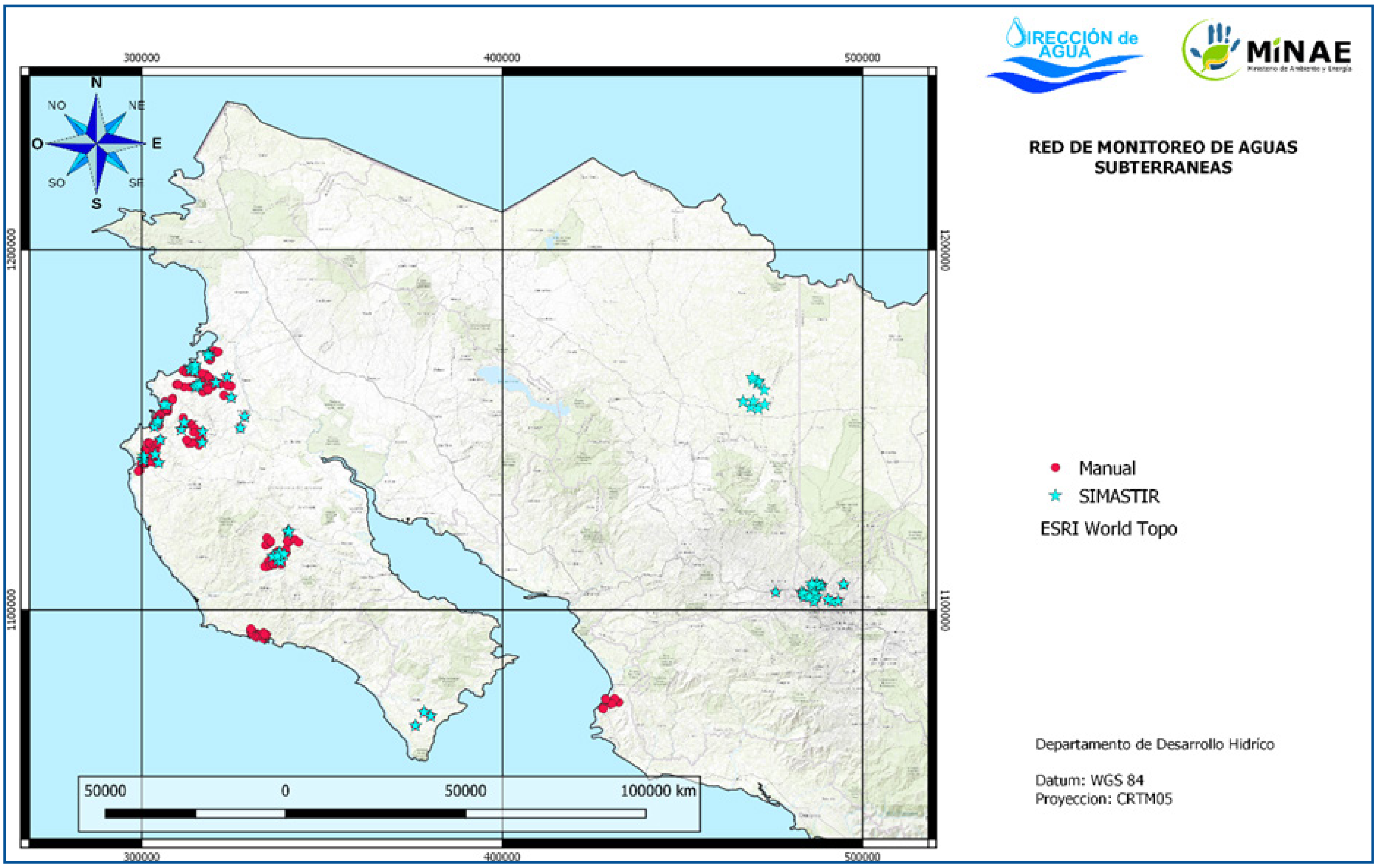


Fig. 33 – Groundwater Monitoring Network of Costa Rica (source: DA under MINAE)

PROCESSING AND DISSEMINATION

Reports made by DA and CTI Aquifers Management are available online. Unprocessed records can be obtained from DA by request. Other detailed data from the monitoring sites can be seen using the SINIGIRH map viewer.

Sources

- **Aquifer Management, Water Directorate (DA) of Costa Rica** - http://www.da.go.cr/gestion-de-acuiferos;
- **Feedback from DA** - received on 06-02-2020;
- **Feedback from DA (answer to form)** - coordinated by CeReGAS and received in 2019;
- **Sardinal Aquifer documents** - http://www.da.go.cr/documentos-acuifero-sardinal;
- **SINIGIRH map viewer** - http://mapas.da.go.cr/mapnew.php; and
- **Ministry of Environment and Energy of Costa Rica (MINAE), Water Directorate (DA), 2017. Real Time Groundwater Monitoring System (SIMASTIR), in Spanish** - Unpublished report. 15 pages.

El Salvador

Capital city: San Salvador
Inhabitants: 6 Million

INSTITUTIONAL SETTING AND PURPOSE

The Ministry of Environment and Natural Resources (MARN) has constitutional power of protection, conservation and recovery of the environment with a specific mandate for the protection of water resources.

In 2007, MARN, through the former National Service of Territorial Studies, SNET (currently the General Directorate of the Observatory of Threats and Natural Resources, DOA) and the European Union, with the project Strengthening Environmental Management of El Salvador (FORGAES), launched the first network of groundwater monitoring wells in the metropolitan area of San Salvador and the Zapotitán Valley, which has been improved through several initiatives promoted by the Hydrology Management Office of MARN. The objective of the network is to provide data on the long-term status and trends of the national groundwater resource.

CHARACTERISTICS OF THE NETWORK

The network currently has 32 monitoring wells that register groundwater levels automatically using data loggers every 8 hours. On average, there are 8 years of records of groundwater levels in 17 of these wells. In 2018 and 2019, 15 new monitoring wells were drilled, which were provided with the equipment to perform automatic measurement of piezometric level and temperature.

Additionally, there is a monitoring network of around 100 hand dug wells where groundwater levels are measured manually. Water sampling for physical-chemical characterization is carried out twice a year (once during dry season and once during wet season). For these wells a record of 7 years of measurement is present.

PROCESSING AND DISSEMINATION

The data are processed by implementing time series analysis. The information on groundwater levels and physical-chemical parameters is published on-line via the Water Information System (SIHI), figure 34. SIHI was designed and developed by the MARN in collaboration with the Spanish Agency for International Cooperation for Development (AECID) through the Cooperation Fund for Water and Sanitation (FCAS).

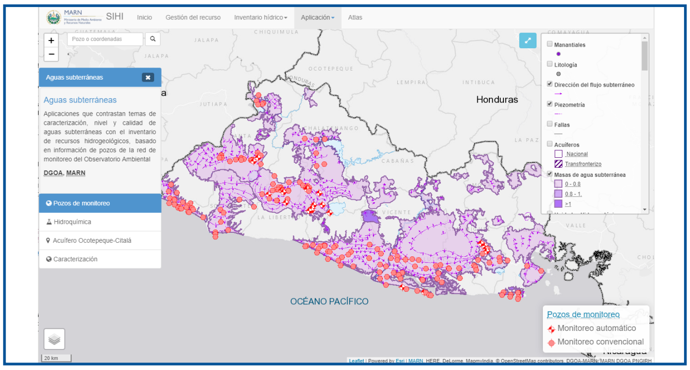


Fig. 34 – Web platform of SIHI

Sources

- **Feedback from MARN -** received on 29-01-2020;
- **Feedback from MARN (answer to form)** - coordinated by CeReGAS and received in 2019;
- **Ministry of the Environment and Natural Resources (MARN)** - http://www.snet.gob.sv/ver/comunicacion+social/noticias+y+temas+de+interes/noticias/ano+2007/inauguracion+de+la+red+de+monitoreo+de+aguas+subterraneas;
- **MARN, 13-09-2019. Rocks and Ashes Unveil Eruptive History of the San Salvador Volcano** - https://www.marn.gob.sv/rocas-y-cenizas-desvelan-historia-eruptiva-del-volcan-de-san-salvador/;
- **MARN Transparency Portal, Groundwater Monitoring Network** http://www.marn.gob.sv/red-de-monitoreo-de-aguas-subterraneas;
- **MARN Transparency Portal, Groundwater -** http://www.marn.gob.sv/agua-subterranea; and
- **MARN Water Information System (SIHI) -** http://srt.snet.gob.sv/sihi/public/app/1/pozosmonitoreo.

Mexico

Capital city: Mexico City
Inhabitants: 128 Million

INSTITUTIONAL SETTING AND PURPOSE

The National Water Commission (CONAGUA) of Mexico is an administrative, technical, consultative and decentralized agency of the Ministry of Environment and Natural Resources (SEMARNAT). CONAGUA is responsible for administration of national water resources, management and control of hydrological systems and promotion of social development. It also manages the national groundwater monitoring network.

CHARACTERISTICS OF THE NETWORK

The national groundwater monitoring network is composed of more than 12,000 wells. These wells monitor 370 aquifers in total, which represent 57% of all Mexican aquifers. CONAGUA also carries out the management and assessment of collected data.

PROCESSING AND DISSEMINATION

CONAGUA maintains a web portal for the Piezometric Monitoring Network, figure 35. It was designed by the Water Geographical Information Sub-Directorate (SIGA) with the aim of offering a spatial information analysis platform populated with geo-referenced data on groundwater monitoring to CONAGUA users.

By clicking on a well icon in the platform, one can access metadata and a time-series graph of the groundwater level (when there is enough piezometric information to generate the hydrograph). Data are not available for downloading. The platform shows the map of Mexican aquifers with available metadata for each aquifer.

Additionally, SIGA designed the Geographic Information System for Aquifers and Watersheds of Mexico (SICAGUA). This system offers users a visualization of geographic elements and serves as a support in the determination of water rights payment, figure 36. Available layers are: availability of aquifers, type of climate, surrounding seas, urban localities, rural locations, states, municipalities, water bodies, major rivers, surface water use, groundwater use, and discharge of wastewater.

Fig. 35 – Groundwater monitoring wells in Mexico. Source: SIGA

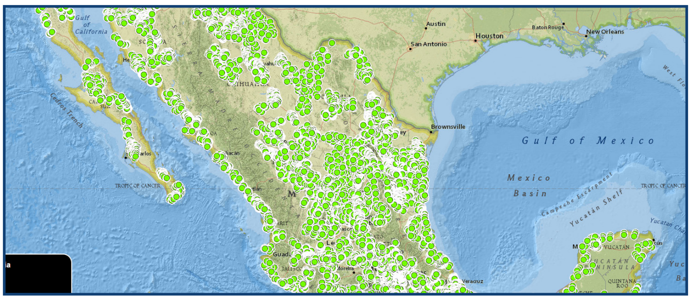


Fig. 36 – SICAGUA web platform

Sources

- **GGMN Workshop Latin America 2013** - GeoVisor of CONAGUA;
- **National Water Commission (CONAGUA)** - https://www.gob.mx/conagua;
- **Piezometric Monitoring Network** - https://sigagis.conagua.gob.mx/rp; and
- **SICAGUA web platform** - https://sigagis.conagua.gob.mx/aprovechamientos.

Paraguay

Capital city: Asunción
Inhabitants: 7 Million

INSTITUTIONAL SETTING AND PURPOSE

The Ministry of the Environment and Sustainable Development (MADES), former Secretary of the Environment (SEAM) is a government agency responsible for policymaking, coordination, supervision and implementation of environmental actions, programs and projects concerning preservation and management of natural resources. In water management, MADES collaborates with the National Environmental Sanitation Service (SENASA), a government entity under the Ministry of Public Health and Social Welfare.

The General Directorate of Protection and Conservation of Water Resources (DGPCRH) of the MADES is in charge of monitoring the Patiño Aquifer, in conjunction with SENASA. Groundwater levels are monitored to understand impacts of growing aquifer exploitation from industry, households and agriculture.

CHARACTERISTICS OF THE NETWORK

Thanks to international cooperation (Inter-American Development Bank), there is a groundwater monitoring plan for the Patiño Aquifer since 2018. This plan includes a network of 47 wells for piezometric observation, where seven of them are equipped with data loggers for automatic recording of water levels and physical parameters. From these seven wells, four have data available on the website of the Directorate of Meteorology and Hydrology (DMH). The remaining 3 wells are in an adaptation stage in order to be available on the platform as well. Monitoring of the Patiño aquifer has been carried out since 2006, with an irregular frequency of data collection both regarding groundwater quantity and quality. However, in 2014 there were improvements in the data collection. In total, 30 of the 47 wells are fully operational, while the rest are being recovered The piezometers were distributed covering the upper, middle and lower basins of the Patiño aquifer area.

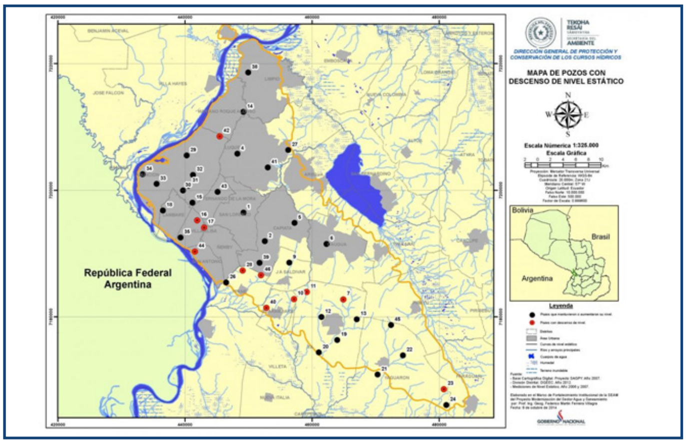


Fig. 37 – Location of monitoring wells in the Patiño aquifer. Black boreholes represent stable water level and red boreholes show decreasing water levels. Source: SEAM

PROCESSING AND DISSEMINATION

There are 2 hydrogeological databases of 550 and 665 wells respectively available in Excel and PWIS (Paraguay Well Information System) formats. Each well has a unique identifying number, with a corresponding name.

PWIS contains information on water level, discharge and water quality, but also information on lithology and well characteristics. Information on this is available at the DGPCRH.

Sources

- **Directorate of Meteorology and Hydrology (DMH), Groundwater Levels** - https://www.meteorologia.gov.py/nivel-pozo/;
- **Feedback from the General Directorate of Protection and Conservation of Water Resources (DGPCRH), MADES** - received on 06-10-2020;
- **GGMN Workshop Montevideo (2013)** - https://www.un-igrac.org/news/regional-ggmn-workshop-latin-america-held-montevideo;
- **Inter-American Development Bank. Study of Water Resources and Climate Vulnerability of the Patiño Aquifer (in Spanish), information provided by CeReGAS** - https://publications.iadb.org/publications/spanish/document/Estudio_de_recursos_h%C3%ADdricos_y_vulnerabilidad_clim%C3%A1tica_del_acu%C3%ADfero_Pati%C3%B1o_es.pdf; and
- **SEAM 2016** - Modernization of the Potable Water and Sanitation Sector Project (PMSAS 7710-PY).

Peru

Capital city: Lima
Inhabitants: 32 Million

INSTITUTIONAL SETTING AND PURPOSE

The National Water Authority (ANA) is the governmental body responsible for the national management of water resources.

CHARACTERISTICS OF THE NETWORK

The groundwater monitoring network of Peru consists of 6,901 wells, of which 3,491 monitor groundwater levels and 3,410 groundwater quality. From the groundwater level monitoring network, 150 wells collect data automatically and the rest is operated manually.

PROCESSING AND DISSEMINATION

The ANA, through the National Water Resources Information System (SNIRH), manages the Groundwater Observatory. It is a public platform with the map viewer and information on the wells of Peru, figure 38. The location of a well, its metadata with coordinates are provided when a user selects a well from a certain Water Administrative Authority and an aquifer.

The portal shows 8,470 wells distributed in 7 Local Water Administrations (ALA). However, it is not indicated if these wells are also used for groundwater monitoring.

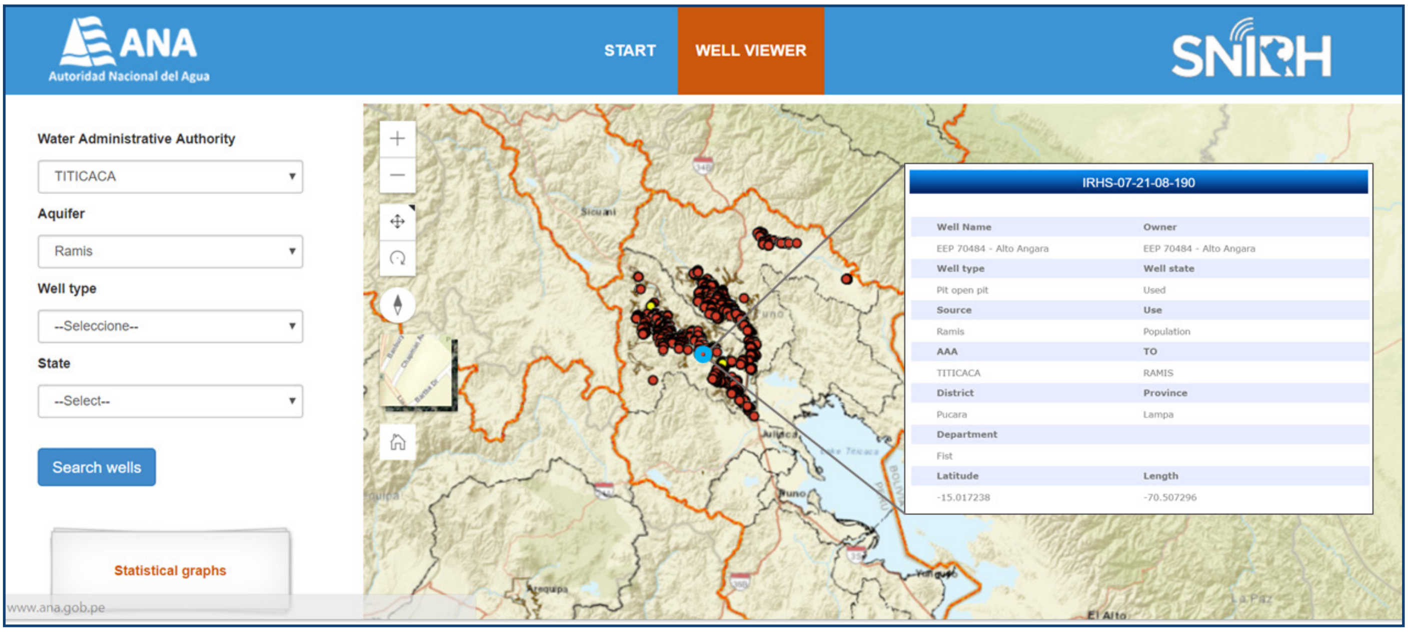


Fig. 38 – Groundwater observation wells in Ramis Aquifer. Source: SNIRH

Sources

- **National Water Authority** - https://www.ana.gob.pe/;
- **GGMN Workshop 2013** - https://www.un-igrac.org/news/regional-ggmn-workshop-latin-america-held-montevideo; and
- **Groundwater Observatory** - http://snirh.ana.gob.pe/visorPozos/.

United States

Capital city: Washington DC
Inhabitants: 328 Million

INSTITUTIONAL SETTING AND PURPOSE

The United States Geological Survey (USGS) Water Resources Mission Area is responsible for providing data and information about the groundwater resources of the United States. Groundwater programmes which USGS undertakes contain various monitoring networks: National networks like the National Ground-Water Monitoring Network (NGWMN), Active Groundwater Level Network and Climate Response Network; Regional Networks like the High Plains Aquifer Monitoring Program with the objective to monitor storage changes in the High Plains Aquifer; state-based networks that are designed to monitor state-wide groundwater conditions; and local networks designed to monitor pumping effects. Some of the national networks are described in the following section.

CHARACTERISTICS OF THE NETWORK

The National Ground-Water Monitoring Network (NGWMN) is a selection of groundwater monitoring wells from Federal, State and local networks across the nation. Currently (as October 2020) it includes 14,378 water level monitoring wells and 3,408 water-quality wells from 32 contributing agencies, figure 39.

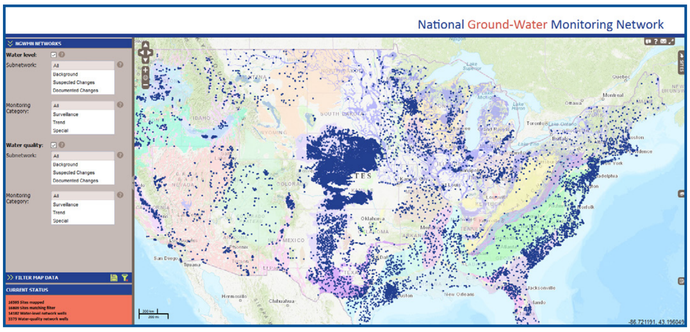


Fig. 39 – National Ground-Water Monitoring Network. Source: USGS

The Active Groundwater Level Network contains data on water levels and well information from more than 18,340 wells. USGS or USGS co-operators take measurements at least once within the past 13 months, figure 40.

The Climate Response Network monitors the effects of droughts and other climate variability on groundwater levels and consisted of about 500 wells in 2006, figure 41. Among them 280 wells were equipped with real-time data loggers, 59 continuous wells measured the level hourly (not available in real time); and about 214 wells measured the levels from monthly to quarterly. The water-level changes in the Network should primarily reflect climatic variability and not human influences.

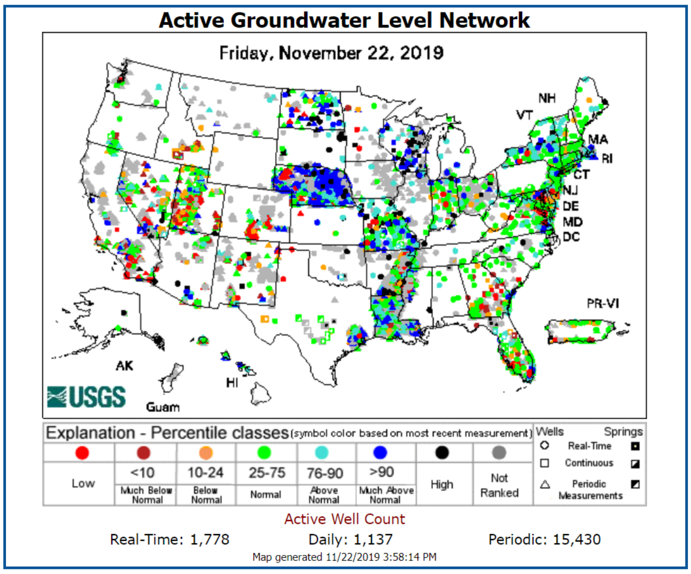


Fig. 40 – Active Groundwater Level Network. Source: USGS

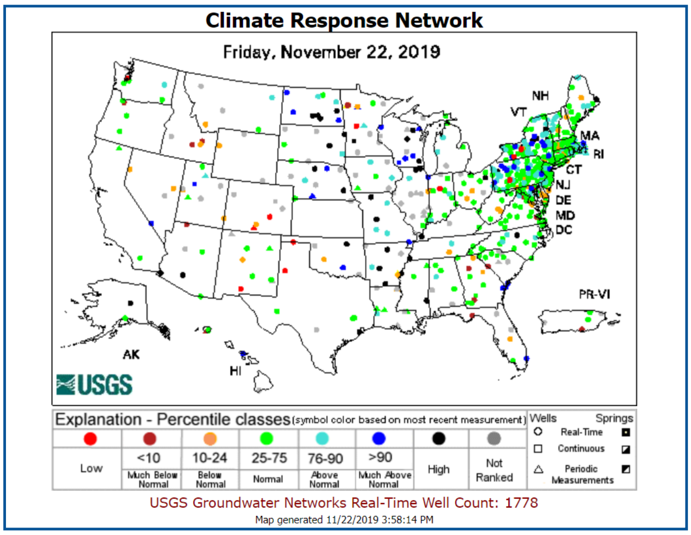


Fig. 41 – Climate Response Network. Source: USGS

The Real Time Groundwater Level Network consists of 1,778 wells with "real time" data transmission instrumentation, figure 42. Real-time data are recorded at 15-60-minute intervals. The data are stored onsite, and then transmitted to USGS offices every 1 to 4 hours, depending on the data relay technique used. During critical events recording and transmission times may be more frequent. Data from real-time sites are sent to USGS offices via satellite, telephone, and/or radio and are available for viewing within minutes of arrival. All real-time data are provisional and subject to revision.

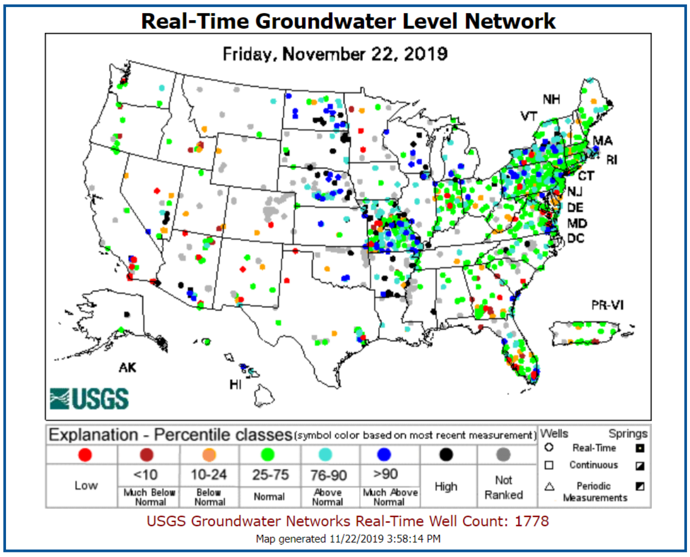


Fig. 42 – Real-Time Groundwater Level Network. Source: USGS

The Below Normal Groundwater Level Network is aimed to analyse wells with groundwater levels below normal, figure 43. The wells must be in an active measurement program, i.e. appears on the Active Groundwater Level Network, and must have 10 or more years of record in the month of the most recent measurement.

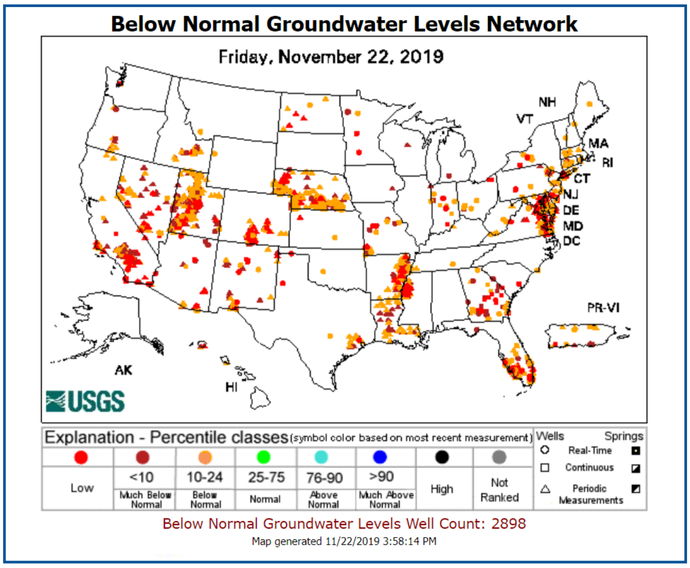


Fig. 43 – Below Normal Groundwater Level Network. Source: USGS

PROCESSING AND DISSEMINATION

Data and information in a national information system are compiled from local/regional, distributed databases of the USGS. Information from all wells is served via the Internet through the National Water Information System Web (NWISWeb) Interface (https://waterdata.usgs.gov/nwis). NWISWeb provides all USGS groundwater data that are approved for public release. The large number of sites is not always user-friendly for all data retrievals in the networks.

Data from the NGWMN can be obtained via the NGWMN Data Portal, which is a web-based mapping application proving access to groundwater data from several databases. The portal contains current and historical data from both groundwater quantity and quality, lithology and well construction.

The USGS Groundwater Watch is an initiative of the Office of Groundwater that provides basic statistics about the groundwater levels collected by the USGS Water Science Centers and from customers through cooperative agreements. National, state and local networks can be accessed via the Groundwater Watch portal. It is noteworthy that this website is going to be deprecated on February 1, 2021, including all the associated network pages. However, USGS will continue collecting and serving data from all of the sites that are monitored as part of those networks, and they are in the process of building a replacement for the Groundwater Watch website which will have similar functionality. Currently, several networks are presented in beta viewers (see Sources).

Active Groundwater Level Network

The water levels (most recent measurements) are classified as much below normal (<10-percentile), below normal (between 10-24 percentiles), normal (between 25-75 percentiles), above normal (between 76-90 percentiles), and much above normal (>90-percentile). The symbol "High" indicates that highest median of the month of the most recent data value is the closest statistic to the most recent data value.

From the Groundwater Watch portal, a user can first select a state of the interest, then a new dialog opens with the map of that state and list of counties with all the monitoring sites for groundwater levels and spring discharges, figure 44. The statistics of a selected well is available in a graphical form, figure 45. Moreover, the information on daily and periodic groundwater data together with the whole period of records are included in the USGS Well Information section.

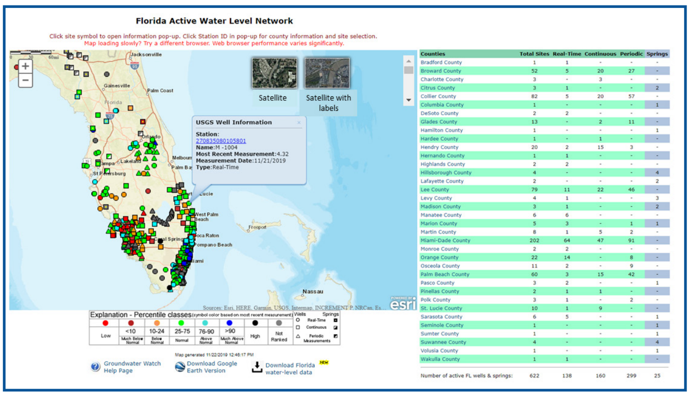
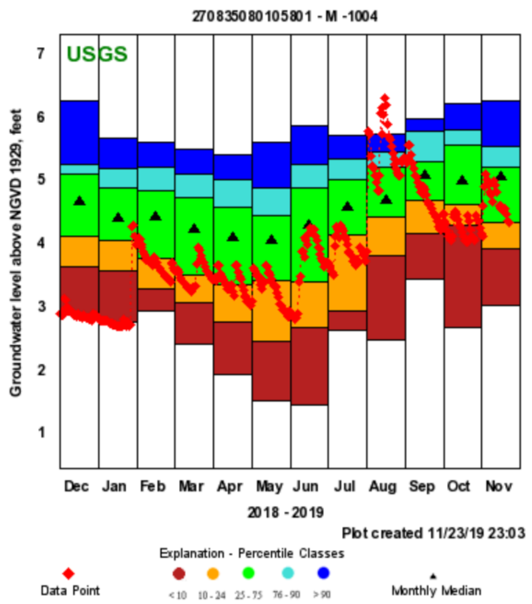


Fig. 44 – Florida Active Groundwater Level Network (right) and list of counties in Florida with monitoring sites (right). Source: USGS

Site Statistics



Most recent data value: 4.22 on 11/24/2019
Period of Record Monthly Statistics for 270835080105801
Groundwater level above NGVD 1929, feet
All Approved Continuous & Periodic Data Used In Analysis
Note: Highlighted values in the table indicate closest statistic to the most recent data value.

Month	Lowest Median	10th %ile	25th %ile	50th %ile	75th %ile	90th %ile	Highest Median	Number of Years
Jan	2.75	3.56	4.04	4.40	4.87	5.18	5.67	34
Feb	2.92	3.29	3.75	4.42	4.83	5.20	5.59	35
Mar	2.40	3.07	3.50	4.21	4.73	5.09	5.49	34
Apr	1.93	2.75	3.35	4.08	4.58	5.01	5.41	34
May	1.50	2.46	3.41	4.05	4.43	4.88	5.59	35
Jun	1.44	2.67	3.38	4.29	4.88	5.25	5.86	33
Jul	2.62	2.92	4.13	4.56	5.00	5.34	5.71	33
Aug	2.48	3.80	4.41	4.67	5.20	5.44	5.73	33
Sep	3.43	4.15	4.68	5.07	5.28	5.77	5.97	33
Oct	2.66	4.28	4.61	4.98	5.56	5.79	6.20	35
Nov	3.02	3.91	4.32	5.04	5.20	5.52	6.26	35
Dec	2.87	3.62	4.12	4.66	5.09	5.24	6.25	35

.As of 11/23/2019 06:37-2

Statistics Options

View month/year statistics

Fig. 45 – Below Normal Groundwater Level Network. Source: USGS

The most recent water-level measurement that belongs to the 24-percentile in the month of measurements over the period of record of the well is used for the analysis. If the measurement is lower than the 10-percentile, the well will be classified as “much below normal”.

Climate Response Network

The snap-shot map is available on the Groundwater watch platform. Only wells having at least 10 years of measurements in a given month are considered for analysis and coded with colours to ensure that the calculated percentiles are representative of historical conditions. There are eight categories of ground-water levels: a new high for the month (black), greater than the 90th percentile (dark blue), 76th–90th percentile (light blue), 25th–75th percentile (green), 10th–24th percentile (orange), less than 10th percentile (brown), and new record low for the month (red), figure 41. The symbol is grey when the most recent measurement is more than 45 days old or less than 10 years of data are available.

National Aquifer Composite Hydrographs

As one of the methods composite water-level hydrographs are used to report on the United States’ major aquifers in which water levels are declining, increasing or stable. Composite hydrographs provide a general overview of water levels in the Principal Aquifers, and they are useful to determine trends in them.

A composite water level is an average water level calculated from a group of index wells. It uses the median water level for the period of interest (annual or monthly) for each index well and then averages all index wells for the particular year or month. The composite water levels representing the average or mean water level of all the index wells is then presented on a hydrograph, figure 45, left.

The composite hydrographs minimize the effects of local or random fluctuations. The identification of appropriate index wells is an important factor. The index wells should come from an area that is similar in some hydrologic condition.

To calculate the groundwater level composite hydrographs for the Principal Aquifers of the United States, different factors are taken into account:

- The period used for the analysis is a moving 30-year hydrograph from the most recent year of record;
- Only index wells with no missing records are used, i.e. every index well has at least one measurement for every year in the 30-year period;
- There must be at least 9 index wells for a Principal Aquifer that meet the period of record criteria and have a reasonable areal distribution through the aquifer. The reasonable areal distribution is defined qualitatively;
- The variable calculated for each index well is the median water level for the year. The annual median water level is always the median of daily values (if exist) and periodic measurements;
- Data are presented in Below Land Surface values.

The advantage of the method is that the applied criteria are simple and there is no need to assess each potential well in the aquifer system. The disadvantage is that the wells might not be evenly spaced, and monitored for specific stresses that are not appropriate to represent the whole aquifer. By normalizing the original hydrograph, the composite annual percent variation can be calculated, figure 45, right. The example on how to calculate the normalized value for a single well, for one year is presented in figure 46. Later, the mean or median will be calculated considering all the wells for every year, and the composite annual median percent variation graph will be generated.

California Coastal Basin Aquifer
Well: 340655117184005
Station Water-Level Index for Calendar Year 1988

$X = 64.74$

$X_{mean} = 156.01$

$X_{max} = 237.18$

$X_{min} = 64.74$

$$X_{norm} = (64.74 - 156.01) / (237.18 - 64.74) * 100 * (-1)$$

$$X_{norm} = (-91.27) / (172.44) * 100 * (-1)$$

$$X_{norm} = 52.93$$

Fig. 46 – Calculation of a normalized value for the Well: 340655117184005

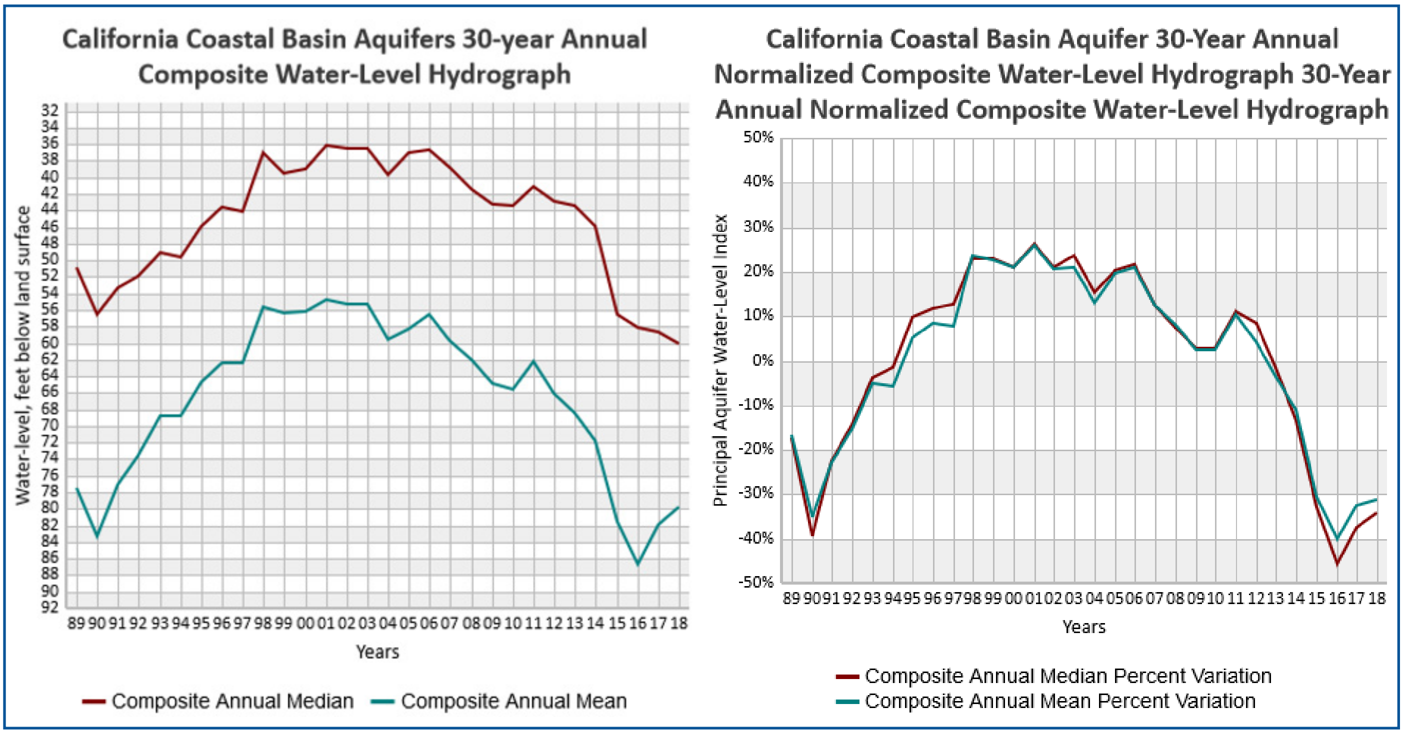


Fig. 47 – Example of composite hydrograph (left) and example of normalized composite hydrograph (right). Source: USGS

Sources

- **Active Groundwater Level Network** - https://groundwaterwatch.usgs.gov/default.asp;
- **Active Groundwater Level Network** - https://waterdata.usgs.gov/networks/AGL/ (beta release);
- **Below Normal Groundwater Levels** - https://waterdata.usgs.gov/networks/LWL/;
- **Climate Response Network (Fact Sheet)** - https://pubs.usgs.gov/fs/2007/3003/pdf/2007-3003-lowres.pdf;
- **Climate Response Network** - https://waterdata.usgs.gov/networks/CRN/ (beta release);
- **Composite Water-Level Hydrographs (main page)** - https://groundwaterwatch.usgs.gov/compositehome.asp;
- **Composite Water-Level Hydrographs (complete description)** - https://groundwaterwatch.usgs.gov/composite/help/compositewaterlevels_helpdocument_7-7-2016.htm;
- **Composite Water-Level Hydrographs (alternative description)** - https://groundwaterwatch.usgs.gov/composite/help/CompositeGroundwaterLevelHelpDocument.docx.html;
- **Feedback from USGS, Water Resource Mission Area** - received on 01-10-2020;
- **National Ground-Water Monitoring Network (NGWMN), main page** - https://cida.usgs.gov/ngwmn/;
- **NGWMN Data Portal** - https://cida.usgs.gov/ngwmn/index.jsp;
- **USGS Groundwater Watch** - https://groundwaterwatch.usgs.gov/usgsgwnetworks.asp (interim version);
- **USGS Groundwater Watch. California Coastal Basin Aquifer Composite Hydrographs (as example)** - https://groundwaterwatch.usgs.gov/compositeaquifers.asp?ncd=CCB;
- **USGS Groundwater Watch. Site Number: 270835080105801 - M -1004 (as example)** - https://groundwaterwatch.usgs.gov/AWLSites.asp?mt=g&S=270835080105801&ncd=awl; and
- **USGS Water Data for The Nation Blog** - https://waterdata.usgs.gov/blog/.

Uruguay

Capital city: Montevideo
Inhabitants: 3.4 Million

INSTITUTIONAL SETTING AND PURPOSE

The Ministry of Housing, Territorial Planning and Environment (MVOTMA) is responsible for the design and implementation of public water policies in Uruguay. The National Water Directorate (DINAGUA) under the MVOTMA is in charge of management, use and control of water resources with respect to extraction volumes, and the National Environment Directorate (DINAMA) is responsible for the quality of the water resources.

Within the framework of the National Water Plan (Plan Nacional de Aguas), approved in July 2017, a groundwater quality and quantity monitoring programme was proposed to be established. Its purpose is to monitor the status, quantity and the quality of the surface and groundwater resources through the knowledge of hydro-meteorological and environmental variables. Currently, there is no national groundwater monitoring network in Uruguay. Nevertheless, monitoring of groundwater is carried out locally.

CHARACTERISTICS OF THE NETWORK

The National Directorate of Mining and Geology (DINAMIGE) has been monitoring the Raigón Aquifer since 1986 and measuring mainly the groundwater level, conductivity and pH in approximately 40 wells twice a year (autumn and spring). Based on these measurements, a report is made and disseminated via the agency's website.

During 2013, DINAMIGE also resumed the monitoring of groundwater levels in the Salto-Arapey Aquifer that had been suspended in 1999.

Fig. 48 – GGMN workshop in 2013

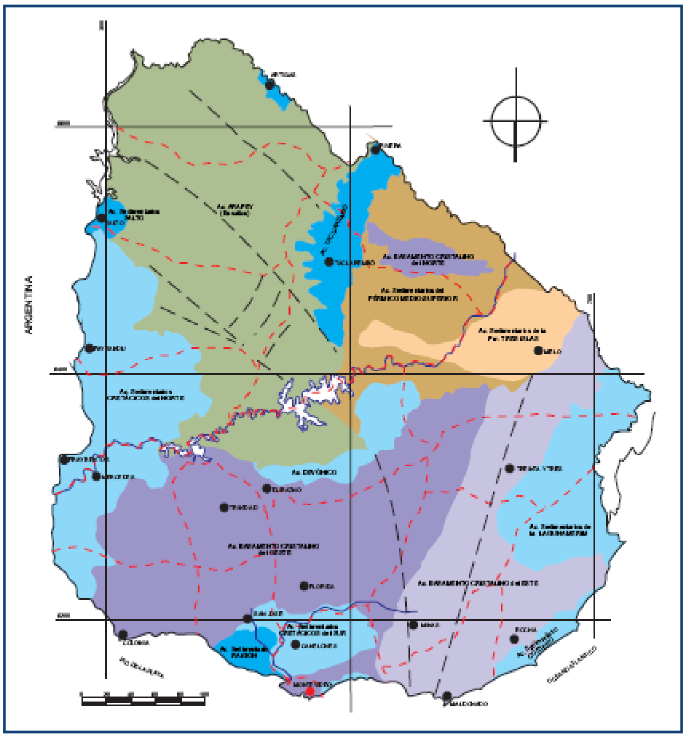


Fig. 49 – Map of Aquifers of Uruguay

Sources

- **Feedback from CeReGAS (Regional Centre for Groundwater Management in Latin America and the Caribbean)** - received throughout 2019;
- **GGMN Workshop Montevideo** - 2013; and
- **Ministry of Industry, Energy and Mining. Monitoring of static levels & physical-chemical parameters in Raigón aquifer** - https://www.miem.gub.uy/mineria-y-geologia/monitoreo-del-nivel-estatico-y-medida-de-parametros-fisico-quimicos-en-el-1.

Venezuela

Capital city: Caracas
Inhabitants: 28 Million

INSTITUTIONAL SETTING AND PURPOSE

The National Institute of Meteorology and Hydrology (INAMEH) is responsible for integrating meteorology and hydrology services offered by various Venezuelan governmental institutions. INAMEH is currently the institution in charge of the groundwater monitoring in Venezuela.

CHARACTERISTICS OF THE NETWORK

Hydrogeological and socio-economic studies conducted in Venezuela prior 2011 concluded that the national monitoring network located to the north of the Orinoco River should have 1,448 wells spread over 750 localities.

PROCESSING AND DISSEMINATION

The INAMEH has a portal where maps of the minimum, mean and maximum groundwater levels can be found. To access the information, a region and state or federal entity of interest must be chosen, and then the thematic maps of water levels will be displayed.

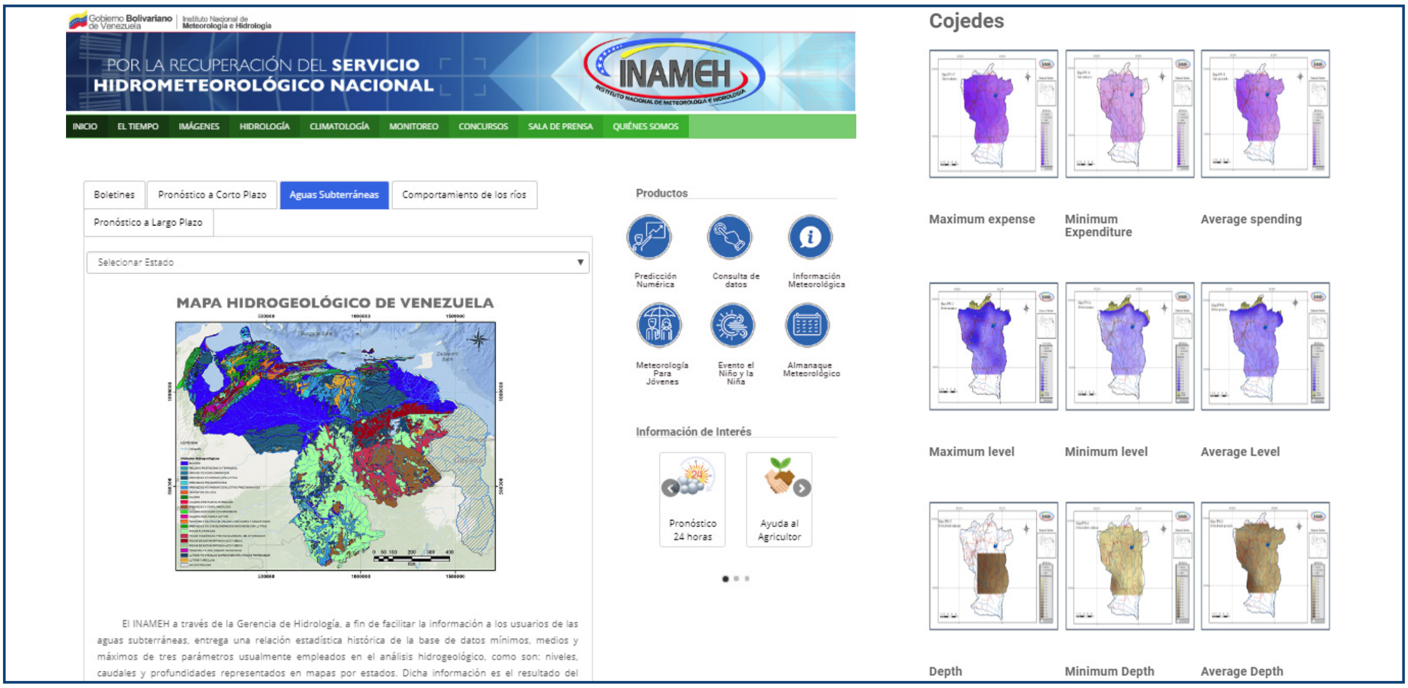
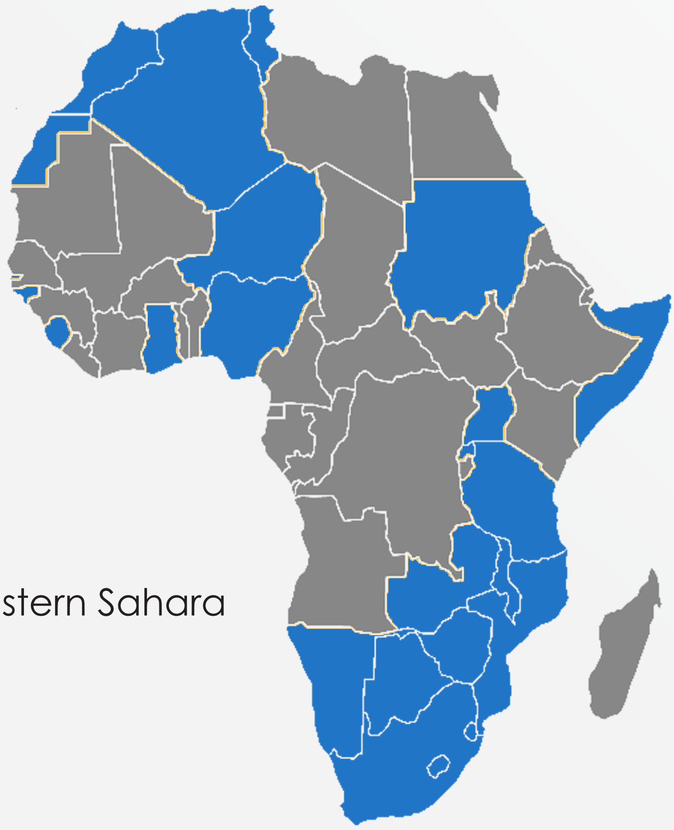


Fig. 50 – Hydrogeological map of Venezuela (left) and groundwater level maps for Cojedes State. Source: INAMEH Portal

Sources

- **Decarli, F. 2011. Estado de las Aguas Subterráneas en Venezuela** - http://avias-aguassubterraneas.blogspot.com/2011/10/estado-de-las-aguas-subterraneas-en.html; and
- **INAMEH** - http://www.inameh.gob.ve/web/hidrologia2/hidrologia.php (no longer functioning).

AFRICA



Algeria

Capital city: Algiers
Inhabitants: 43 Million

INSTITUTIONAL SETTING AND PURPOSE

The Ministry of Water Resources (MRE) is responsible for creating the institutional conditions to improve the management of public water services. Institutional consultation with the sectors is ensured by an advisory body called National Water Council (CNL).

The National Agency for Hydraulic Resources (ANRH) is the national agency in charge of decision-making for groundwater resources in Algeria and conducting scientific and technical activities. ANRH with the Agency of Hydrographic Basins (ABH) are in charge of quantity and quality groundwater monitoring, including the collection, processing and updating of data and information on groundwater resources.

ANRH ensures the update of the water points inventory, the piezometric monitoring of groundwater, prospection, and mathematical model to facilitate the management of the resource.

CHARACTERISTICS OF THE NETWORK

The monitoring network maintained by ANRH is comprised of 500 observation points. Monitoring campaigns are done twice a year, at low and high water-level points.

North Western Sahara Aquifer System (NWSAS) consultation mechanism established 11,166 water points of the monitoring system in Algeria, Tunisia and Libya by 2008 where the data on piezometric heads, water abstraction, drawdown, water quality was collected to manage shared groundwater resources.

PROCESSING AND DISSEMINATION

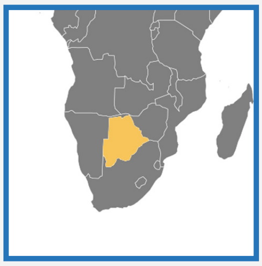
In this area, ANRH regularly publishes yearly reports of geophysical studies, directories of hydrogeological studies, inventories of water points, and inventory of piezometers. The collected information supports specific hydrogeological studies and the development of thematic maps such as: hydrogeological maps, piezometric maps, vulnerability maps of groundwater resources, aquifer systems maps, etc.

Data from the NWSAS consultation mechanism is included in the Algeria Water Sector M&E Rapid Assessment Report.

Sources

- **Agence Nationale des Ressources Hydrauliques (ANRH)** - http://www.anrh.dz;
- **CEDARE, 2014. Algeria Water Sector M&E Rapid Assessment Report. Monitoring & Evaluation for Water in North Africa (MEWINA) Project, Water Resources Management Program, CEDARE** - http://web.cedare.org/wp-content/uploads/2005/05/Algeria-Water-Sector-Monitoring-and-Evaluation-Rapid-Assessment-Report.pdf;
- **Chabour, N, Mebrouk, N, Hassani, I H, Upton, K, Ó Dochartaigh, B É and Bellwood-Howard, I. 2018. Africa Groundwater Atlas: Hydrogeology of Algeria. British Geological Survey. Accessed 02-07-2019** - http://earthwise.bgs.ac.uk/index.php/Hydrogeology_of_Algeria; and
- **Guyomard, 2011. Concerted management of transboundary groundwater (In French)** - https://www.oieau.fr/eaudoc/system/files/Guyomard_synthese_finale-1_0.pdf.

Botswana



Capital city: Gaborone
Inhabitants: 2 Million

INSTITUTIONAL SETTING AND PURPOSE

Groundwater level monitoring in Botswana is carried out by the Ministry of Land Management, Water and Sanitation Services (MLMWS, formerly the remit of the Ministry of Minerals, Energy and Water Resources, MMEWR).

The Department of Water and Sanitation monitors both natural (undisturbed) areas and pumping (disturbed) areas. Formerly, the natural areas were monitored by the Department of Geological Survey (DGS), which has been transformed into Botswana Geoscience Institute. The objectives of monitoring are (i) to observe long-term groundwater level behaviour under natural conditions and to collect data for future economic development and resources management, and (ii) to observe long-term groundwater level behaviour under pumping conditions to analyse changes and aquifers' responses to stresses. DWS also advises the Water Apportionment Board for licenses of large water users. Large water users have to report annually, although without the obligation to submit the relevant data to the Department of Water Affairs (DWA).

Furthermore, the Ministry of Agriculture oversees the livestock watering and large-scale irrigation, and the Water Utilities Company (WUC, parastatal) is the drinking water supply authority responsible for abstraction, distribution, and monitoring of pumped wellfields.

WUC is responsible for compliance monitoring in and around wellfields and monitoring the performance of boreholes. Large water users carry out compliance monitoring as well.

CHARACTERISTICS OF THE NETWORK

The national groundwater monitoring network has approximately 1000 piezometers, and in general the measurements are taken manually and monthly. In addition, WUC has approximately 100 data loggers installed in about 10 wellfields.

PROCESSING AND DISSEMINATION

The Department of Water and Sanitation uses its web-based Integrated Groundwater Resource Data Management System (IGWRMS) for storage and dissemination of borehole completion certificates, dams, river draw offs, and monitoring data (levels, quality and quantity) and information.

Sources

- **Feedback from the Department of Water and Sanitation Botswana** - received on 06-10-2020;
- **IGRAC, 2013. Groundwater Monitoring in the SADC Region, 2013. Overview prepared for the Stockholm World Water Week** - https://www.un-igrac.org/sites/default/files/resources/files/Report_Groundwater%20Monitoring%20in%20SADC%20region.pdf;
- **Farr, J.L. 2017. Groundwater Monitoring Assessment Study Botswana. World Bank GFDRR Final Report** - Report prepared as a collective contribution from DWS (DWA) and WUC as main stakeholders and other stakeholders as Department of Meteorological Services (DMS), Botswana geoscience Institute (BGI), National Disaster Management Office (NDMO), Universities (UB and BUIST), private sector (Debswana, mining companies, industrial enterprises, parastatals), and government ministries and departments;
- **Upton, K, Ó Dochartaigh, B É, Key, R, Farr J and Bellwood-Howard, I. 2018. Africa Groundwater Atlas: Hydrogeology of Botswana. British Geological Survey. Accessed 02-07-2019** - http://earthwise.bgs.ac.uk/index.php/Hydrogeology_of_Botswana; and
- **SADC country visits** - 2017.

Eswatini

Capital city: Mbabane and Lobamba
Inhabitants: 1 Million

INSTITUTIONAL SETTING AND PURPOSE

Groundwater resources are monitored and managed by the Ministry of Natural Resources and Energy through The Department of Water Affairs. As secondary task the Ministry is obliged to supply and manage water in the rural areas of the country. The country has approximately 6,000 boreholes dug for groundwater exploration, the bulk of them for domestic water supply particularly in water stressed areas. Exploration wells are intended for the monitoring of groundwater levels and quality.

Groundwater monitoring is coordinated from the headquarters in Mbabane. A groundwater monitoring plan existed but was curtailed to enable the use of the groundwater boreholes to provide potable water to communities affected by the drought that has been observed over the years. However, groundwater monitoring is being revised through support from the SADC Groundwater Management Institute. A groundwater monitoring project is being piloted with the aim of rolling out to a national scale subject to availability of funds. Considered parameters are water levels, major ions (Ca, Mg, K, Na, Cl, NO3, SO4, HCO3 and CO3), EC, pH, just to name a few.

PROCESSING AND DISSEMINATION

Groundwater levels are supposed to be measured monthly, but they are currently measured only once after the borehole has been drilled. Afterwards, it is the responsibility of the user to monitor the water level, but these values are not communicated to the Ministry in a systematic and harmonised manner.

There is no database to store groundwater monitoring data, however, this would soon be a thing of the past post the ongoing pilot groundwater monitoring project implementation. Data are stored in Excel files and is accessed by staff within the Department with no access to external users.

Fig. 51 – Field visit in Eswatini for SADC project

Sources

- **Feedback from the Department of Water Affairs** - received on 22-10-2020; and
- **SADC country visits** - 2017.

Ghana

Capital city: Accra
Inhabitants: 30 Million

INSTITUTIONAL SETTING AND PURPOSE

In Ghana, the Ministry of Sanitation and Water Resources (MSWR) established in January 2017, through its Water Directorate, coordinates policies, programmes and projects on water resources management, drinking water and water-related sanitation sector. Before 2017, the water sector was part of the Ministry of Water Resources, Works and Housing, and the sanitation sector was part of the Ministry of Local Government and Rural Development.

The Water Directorate collaborates with the Water Resources Commission (WRC), the body mandated to regulate and manage water resources (including groundwater) and to coordinate government policies in relation to them. The WRC mandates data collection institutions such as the Ghana Atomic Energy Commission (GAEC) and the Groundwater Division of the Council for Scientific and Industrial Research – Water Research Institute (CSIR-WRI) to undertake groundwater monitoring programs. Data and information on groundwater level and recently, data on physico-chemical parameters as well as isotopic composition of the monitoring wells in the Volta basin are collected.

The Groundwater Division of the CSIR-WRI had a number of monitoring wells in the Accra Plains which were monitored monthly for several years until it was discontinued in the late nineties due to urbanization and land disputes rendered most of the well locations inaccessible.

CHARACTERISTICS OF THE NETWORK

With the support of the CIDA-funded Hydrogeological Assessment Project of the Northern Regions of Ghana (in the Volta river basin), the Water Resources Commission has achieved the establishment of a groundwater monitoring network and information management system. Other funded projects by the Danish Development Cooperation (DANIDA) and the European Union (EU) installed groundwater monitoring wells in the Tano, Ankobra, Pra and Densu river basins. In all, a total of about seventy (70) wells are installed in the above river basins, thirty-seven (37) of which are located in the Volta basin which are currently being monitored by GAEC on behalf of the WRC.

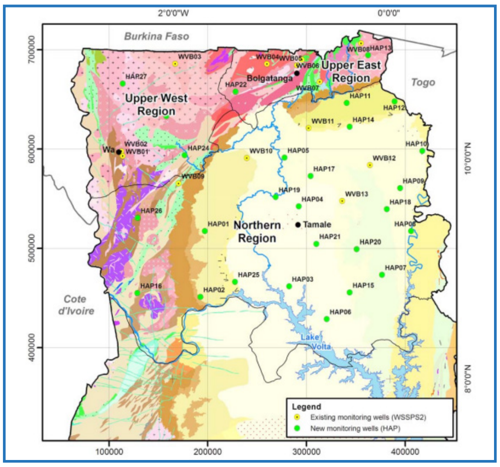


Fig. 52 – Location of the 37 new and existing monitoring wells

PROCESSING AND DISSEMINATION

The raw data of time-series groundwater level of monitoring wells are stored in Water Resources Commission hydrogeological database and are available to the general public usually by request. However, there are yearly reports for each groundwater monitoring campaign which are available at WRC. Data are also stored at CSIR-WRI.

Sources

- **Bibliographic reference: Obuobie, E., Agyekum, W., Appiah-Adjei, E.K., Upton, K., Ó Dochartaigh, B.É. and Bellwood-Howard, I. 2018. Africa Groundwater Atlas: Hydrogeology of Ghana. British Geological Survey. Accessed 02-07-2019** - http://earthwise.bgs.ac.uk/index.php/Hydrogeologyof_Ghana;
- **Feedback from the Groundwater Division of the CSIR WRI** - received on 16-03-2020;
- **Feedback from WRC, Ghana** - received on 07-05-2020;
- **Ministry of Sanitation & Water Resources, Republic of Ghana** - http://mswr.gov.gh/about-us/; and
- **Water Resources Commission of Ghana** - http://www.wrc-gh.org/about-us/.

Guinea-Bissau

Capital city: Bissau
Inhabitants: 1 Million

INSTITUTIONAL SETTING AND PURPOSE

The Directorate General of Water Resources (DGRH) under the Ministry of Energy, Industry and Natural Resources (MEIRN) is the main entity responsible for water supply and sanitation in Guinea Bissau. Other state agencies with responsibilities for water resources are the Ministry of Public Health, the Public Enterprise for Electricity and Water Supply (EAGB), the General Directorate of Energy (DGE), the Inter-ministerial Council for Water Resources (CIMA), the Water Technical Committee, and the Ministry of Agriculture, Forestry, Hunting and Livestock with its Directorate of Rural Engineering Services (DSER).

PROCESSING AND DISSEMINATION

Groundwater data are stored in a national database hosted by the DGRH and visualized with mWater Portal including drilling logs, groundwater levels and groundwater quality, figure 53. The development of this database has been supported by UNICEF.

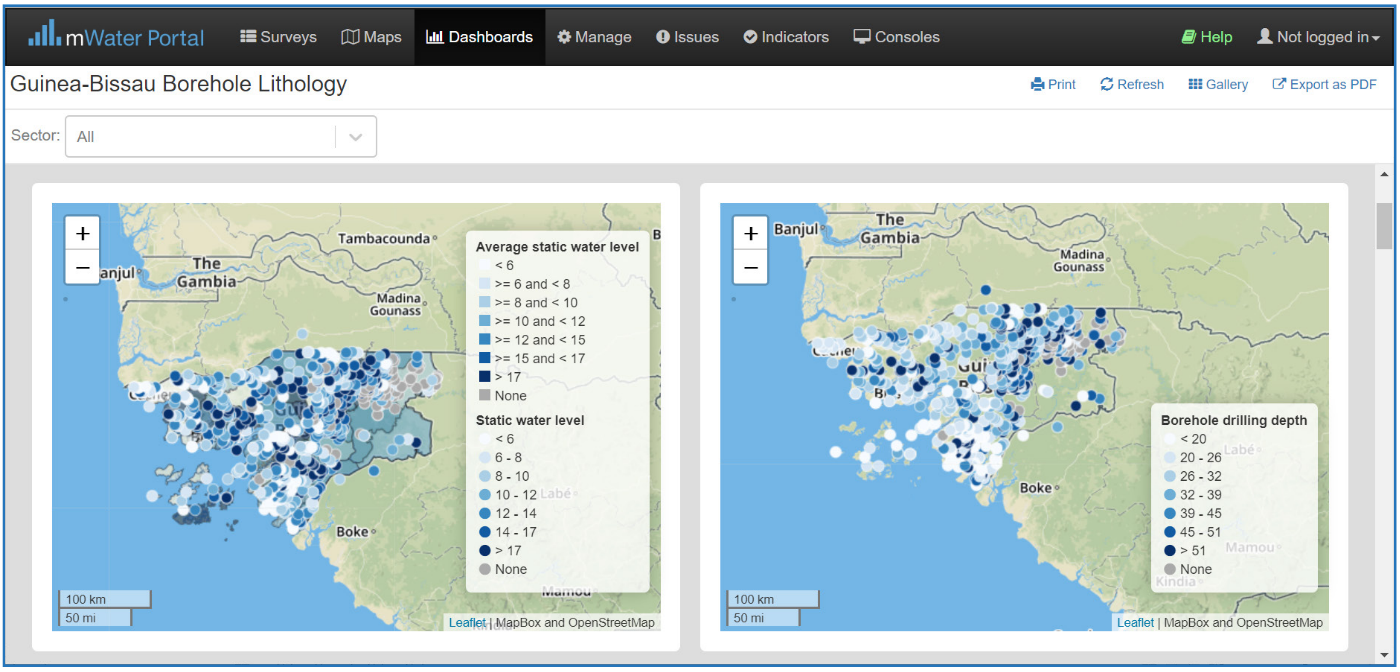


Fig. 53 – Guinea Bissau borehole lithology with static groundwater level information, mWater Portal

Sources

- **Bibliographic reference: Upton, K, Ó Dochartaigh, B É and Bellwood-Howard, I. 2018. Africa Groundwater Atlas: Hydrogeology of Guinea Bissau. British Geological Survey. Accessed 02-07-2019** - http://earthwise.bgs.ac.uk/index.php/Hydrogeology_of_Guinea_Bissau; and
- **Guinea-Bissau Borehole lithology** - https://portal.mwater.co/#/dashboards/9c20165c8763489b85baf898bda1dca3?share=2bb0050028d540298277e50208717545.

Lesotho

Capital city: Maseru
Inhabitants: 2.1 Million

INSTITUTIONAL SETTING AND PURPOSE

The Department of Water Affairs (DWA) in the Ministry of Water is responsible for groundwater monitoring including groundwater levels and groundwater quality. Groundwater monitoring started in the early 1990's as a result of an Italian (funded and executed) project that produced a Lesotho Hydrogeological Map. Boreholes drilled for the purpose of that project became the groundwater monitoring network, without a concrete monitoring plan and specific objectives.

Lesotho is in a process of decentralisation where the monitoring responsibility will be transferred to local communities and where DWA takes the primarily advisory role. Also, Lesotho is implementing the project under SADC-GMI on Expansion of National Groundwater Monitoring network that ends December 2020. This project is aimed at improving what has been done in the 90's with a clear plan of what is being monitored for best quality data on groundwater resources.

CHARACTERISTICS OF THE NETWORK

The network includes officially 130 springs and 60 observation wells, but it is not fully operational, figure 54. In reality, only 30 springs (distributed in 10 districts) and 20 wells (approx. 3 per district) are being regularly monitored.

Both observation wells and springs are monitored every three months. Piezometric levels are measured manually with water level dippers (no data loggers are used).

Monitoring of springs, which are numerous and the main source for rural water supply, is done by regional offices in mountainous areas, and by DWA in lowlands. DWA makes use of data from the Ministry of Health to prioritise springs for sampling. Prioritising is based on 1) population depending on the source, 2) age of water at the source (both data from DWA and regional offices in mountainous areas for rural water supply) and 3) disease trends in population using the source (data from the Ministry of Health).

PROCESSING AND DISSEMINATION

Data of groundwater levels is stored in simple spreadsheets per district. Data are not compiled in a central database.

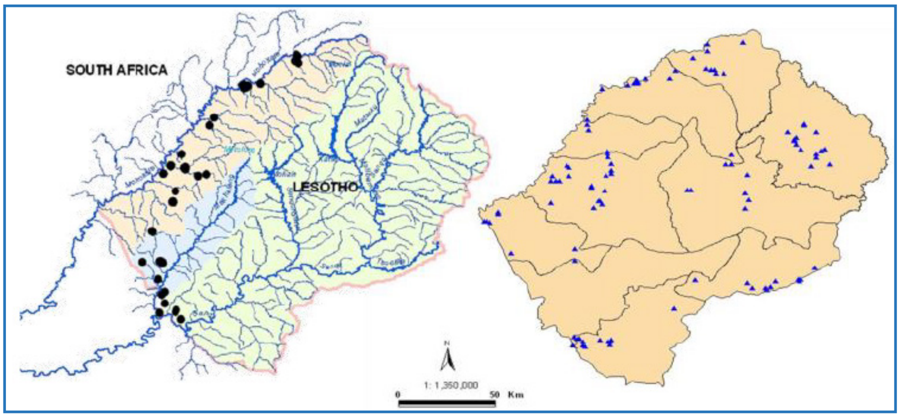


Fig. 54 – Location of boreholes (black dots, left), location of monitoring springs (blue triangles, right)

Sources

- **Department of Water Affairs (DWA), Ministry of Water of Lesotho** - www.water.org.ls/dwa/;
- **Feedback from Department of Water Affairs, Groundwater Division, Ministry of Water of Lesotho** - received on 16-09-20;
- **IGRAC, 2013. Groundwater Monitoring in the SADC Region, 2013. Overview prepared for Stockholm World Water Week** - https://www.un-igrac.org/sites/default/files/resources/files/Report_Groundwater%20Monitoring%20in%20SADC%20region.pdf; and
- **SADC country visits** - 2017.

Malawi

Capital city: Lilongwe
Inhabitants: 18.1 Million

INSTITUTIONAL SETTING AND PURPOSE

The monitoring of groundwater levels is responsibility of the Groundwater Division at the Department of Water Resources (DWR) under the Ministry of Forestry and Natural Resources. The National Water Resources Authority (NWRA), established by the Water Resources Act 2013, will take over this responsibility when it is adequately operationalised.

The national groundwater monitoring network was established in 2009. The objective of the network is to monitor groundwater quality and quantity in Malawi to enable informed decision-making for the development and protection of groundwater resources. The National Water Resources Master Plan, 2017 includes an Annex on Groundwater that describes the hydrogeology of the country, groundwater monitoring and groundwater development.

CHARACTERISTICS OF THE NETWORK

The network includes 75 wells with automatic data loggers. 30 of them were drilled in 2009-2010 and started recorded data automatically in 2013.In total, 36 of the wells were drilled in 2015 and had data loggers installed in 2017. Data for these 66 monitoring wells is recorded every 15 minutes. Groundwater monitoring data downloading from the loggers is ad hoc due to resource constraints. Another 10 monitoring wells were drilled in 2017 and data loggers were installed in 2018 for automatic readings at 9 of them (one was vandalised before installation). The loggers for the latter 9 wells record data every hour.

Groundwater levels are firstly stored into Excel which allows easy processing and visualisation. The Ministry uses Windows Interpretation System for Hydrogeologists (WISH) database developed by the Institute for Groundwater Studies (IGS) and the Water Research Commission (WRC) as a groundwater assessment tool. The data are also stored in Hydstra (which is the main software used for hydrological data analysis in the Ministry) including groundwater level time-series, but there are challenges in using drilling data in Hydstra. Also, challenges with licence requirements for Hydstra and compatibility with drilling data affect its use.

Data are for Ministry's internal use as well as for external use as requested.

Groundwater level time series are analysed via plotting and identification of outliers, trends and gaps, combining precipitation and surface water data.

Sources

- **Departments of the Ministry of Irrigation and Water Development** - http://www.malawi.gov.mw/index.php?option=com_content&view=article&id=13&Itemid=99;
- **Feedback from the Groundwater Division at the Department of Water Resources (DWR), Ministry of Forestry and Natural Resources of Malawi** - received on 22-09-20;
- **Government of Malawi, Department of Water Resources, Transboundary Water Resources Management Unit. National Water Resources Authority (NWRA)** - http://malawi-twrmu.hatfieldgroup.com/en/institutions/national-water-resources-authority; and
- **SADC country visits** - 2017.

Mauritius

Capital city: Port Louis
Inhabitants: 1 Million

INSTITUTIONAL SETTING AND PURPOSE

The Water Resources Unit (WRU) under the Ministry of Energy and Public Utilities is responsible for the assessment, development, management and conservation of water resources in the Republic of Mauritius. On the other hand, the Central Water Authority (CWA) of the Ministry of Energy and Public Utilities has the mission of securing and providing a sustainable water supply service of appropriate quality and at affordable price.

CHARACTERISTICS OF THE NETWORK

Groundwater monitoring consists of 300 wells managed by the WRU and 400 abstraction wells controlled by the CWA.

The frequency of monitoring used to be every month, but currently it has been reduced to once every four months depending on the priority degree. The measurements are mostly manual. Only 13 sites are equipped with data loggers.

The quality of data are checked by senior/experienced personnel without a specific procedure.

There is no database available. However, the groundwater level data can be accessed via reports, and they are available to the public.

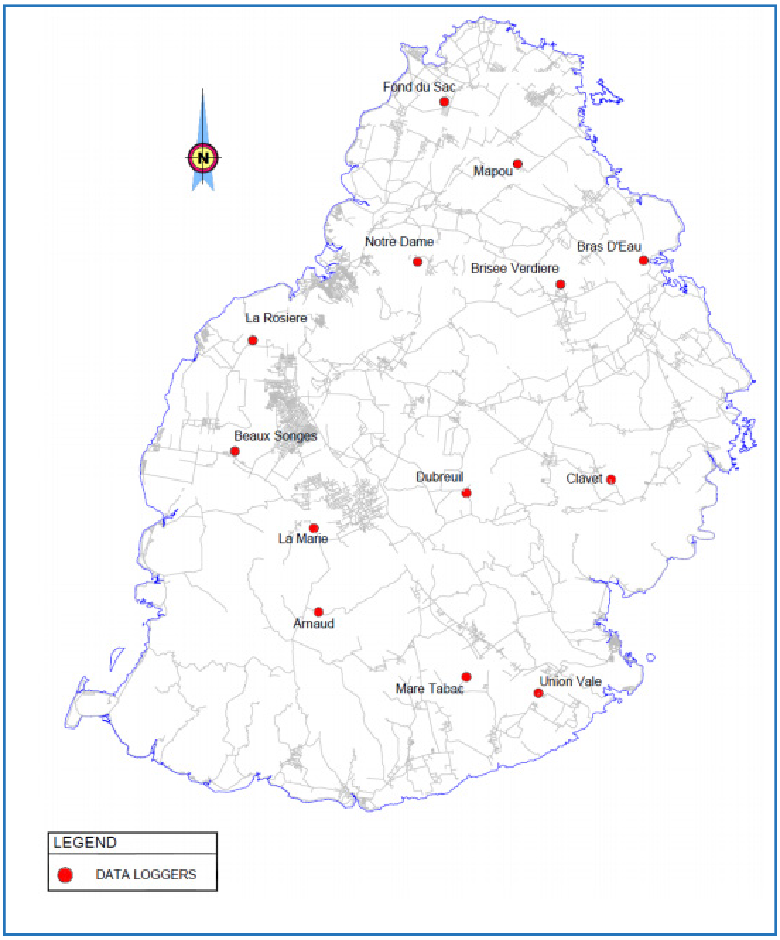
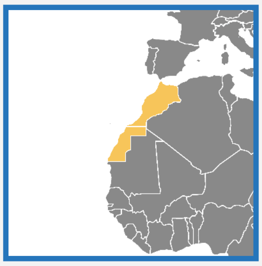


Fig. 55 - Location of data loggers in Mauritius

Sources

- **Hydrology data book** - http://publicutilities.govmu.org/English/Pages/Hydrology-Data-Book-2006---2010.aspx;
- **SADC Project** - Country visits (2017).



Morocco & Western Sahara (Moroccan Sahara)

Capital city: Rabat
Inhabitants: 36 Million

INSTITUTIONAL SETTING AND PURPOSE

The Department of Water under the Ministry of Energy and Mines, Water and Environment (MEM) is responsible for developing and ensuring the implementation of policies in terms of mobilisation, management, preservation and protection of water resources. This is done through nine Basin Hydraulic Agencies (Oum Er Rbia, Moulouya, Loukkos, Sebou, Bou Regreg and Chaouia, Tensift, Souss-Massa-Draa, Guir-Ziz-Rhéris and Sakia El Hamra-Oued Eddahab) and the National Office of Electricity and Drinking Water (ONEE). The Basin Agencies carry out groundwater level and quality monitoring.

PROCESSING AND DISSEMINATION

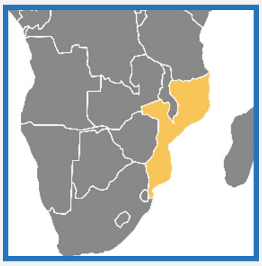
Groundwater level monitoring is carried out monthly in important and overexploited aquifers, and twice per year in other aquifers. The data are stored in databases of the Hydraulic Department of the MEM and the Basin Agencies. Other important background data are stored in universities and research institutes.

Fig. 56 - Well along the Tensift River (right bank), near Marrakech, by: Water Alternatives

Sources

- **Upton, K., Ó Dochartaigh, B.É. and Bellwood-Howard, I. 2018. Africa Groundwater Atlas: Hydrogeology of Morocco & Western Sahara. British Geological Survey. Accessed 02-07-2019** - http://earthwise.bgs.ac.uk/index.php/Hydrogeology_of_Morocco_%26_Western_Sahara_(Moroccan_Sahara).

Mozambique



Capital city: Maputo
Inhabitants: 29.5 Million

INSTITUTIONAL SETTING AND PURPOSE

The National Water Directorate (DNA) under the Ministry of Public Works and Housing and Water Resources (MOPHRH) is in charge of water resources planning and development in Mozambique.

Groundwater monitoring has been decentralised in Mozambique. The country used to be divided in five Regional Water Administrations (ARAs), but due to reforms in the water resources sector, there are now three ARAs. The capital city, Maputo, is located in the most southern ARA called ARA-Sul.

There is no national groundwater monitoring plan but apparently all the ARAs have monitoring networks. ARAs measure water levels (monthly) and groundwater quality (every six months).

Different departments have different databases. The department of water affairs does not support the data handling. When they require data, it is requested from the ARAs. The ARAs do the borehole registration, including geophysical and geological information from the borehole logs, pumping test data, and the coordinates without the elevation.

Access to the data are restricted to the ARAs, but external access can be granted on written request. The main users of the groundwater data are the ARAs, the MOPHRH, universities and consultants.

CHARACTERISTICS OF THE NETWORK

The water agency ARA-Sul has an operational network that consists of 45 groundwater monitoring wells in and around Maputo, figure 57. The network was established to monitor the Greater Maputo Aquifer. Data collection includes groundwater levels, electro-conductivity (EC) and chemical parameters.

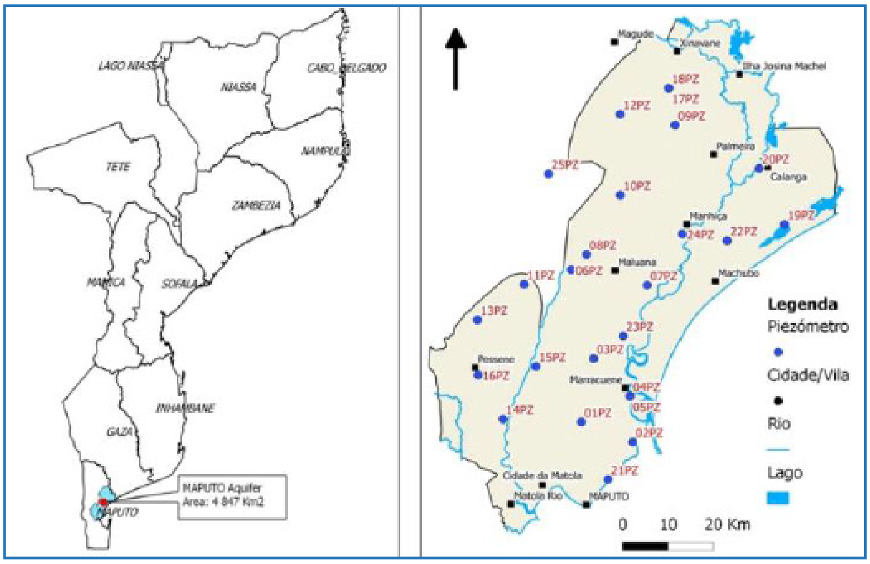
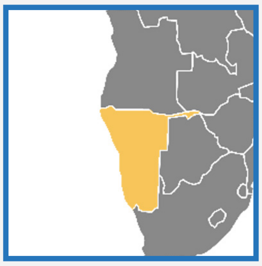


Fig. 57 - Provinces of Mozambique and location of the Maputo Aquifer (left), location of monitoring points part of the ARA-Sul

Sources

- **Chairuca, L., Naafs, A., van Haren, I., Upton, K., Ó Dochartaigh, B.É. and Bellwood-Howard, I. 2018. Africa Groundwater Atlas: Hydrogeology of Mozambique. British Geological Survey. Accessed 02-07-2019** - http://earthwise.bgs.ac.uk/index.php/Hydrogeology_of_Mozambique;
- **Feedback from the Ministry of Public Works, Housing and Water Resources (MOPHRH)** - received on 23-09-20;
- **SADC country visits** - 2017; and
- **IGRAC, 2013. Groundwater Monitoring in the SADC Region, 2013. Overview prepared for the Stockholm World Water Week** - https://www.un-igrac.org/sites/default/files/resources/files/Report_Groundwater%20Monitoring%20in%20SADC%20region.pdf.



Namibia

Capital city: Windhoek
Inhabitants: 2.5 Million

INSTITUTIONAL SETTING AND PURPOSE

The Ministry of Agriculture, Water and Land Reform (MAWLR) through the Directorate of Water Resources Management (DWRM) is responsible for the groundwater monitoring in Namibia. Even though groundwater level monitoring started in Namibia in the 1960s, no formal groundwater monitoring plan at the national level is in place. The ongoing groundwater monitoring in the country is based on MAWF annual plans, the availability of resources and sometimes ad-hoc decisions.

The nation-wide groundwater monitoring has an overall aim of keeping uninterrupted record for possible future evaluation, data collection for dissemination and decision making.

The monitoring network also aims to identify areas of extensive groundwater use and areas of a transboundary significance.

CHARACTERISTICS OF THE NETWORK

Currently, 629 monitoring wells are present in the system. The design of the monitoring network took into account areas with high potential of groundwater resources to monitor and protect them for a sustainable use. The data are collected manually and automatically. The collected data include groundwater levels, groundwater quality sampling and abstraction.

Automatic water level loggers transmit data on daily basis, water level loggers without telemetric connection are read quarterly. Initial borehole installations are also recorded and displayed for easy reference, but changes to the installation are not recorded.

The equipment used in the field is calibrated on every field visit and/or inspection and correlated to the manual measurement in site. Likewise, equipment for the monitoring of groundwater quality are calibrated for use before every collection of samples.

PROCESSING AND DISSEMINATION

Analyses and interpretation is performed through trend analysis and correlation is performed to time-series of piezometric levels. Monitoring data are stored in the National Groundwater Database (GROWAS). Digital records are firstly retrieved in excel spreadsheets and subsequently in GROWAS2.

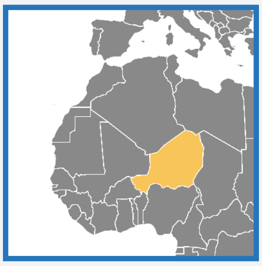
Data collected is checked and verified by the Geohydrology Division of the Department of Water Affairs before entering into the database.

Data are available internally for all relevant staff working and verifying the databases. Overall, data are accessible upon request, depending on the nature of the request. The user must fill a data use disclaimer form, stating the use of the data and confirming that the data will be used for that purpose only. It is not allowed to share data internationally unless it is stated so in the disclaimer form.

Sources

- **Feedback from the Geohydrology Division of the Ministry of Agriculture, Water and Land Reform of Namibia** - received on 15-09-20;
- **Geohydrology Division of the Department of Water Affairs. Groundwater in Namibia: an explanation to the Hydrogeological Map. Unrevised second edition January 2011. ISBN No. 0-86976-571-X** - https://www.bgr.bund.de/EN/Themen/Wasser/Projekte/abgeschlossen/TZ/Namibia/groundwater_namibia.pdf?__blob=publicationFile&v=3;
- **IGRAC, 2013. Groundwater Monitoring in the SADC Region, 2013. Overview prepared for the Stockholm World Water Week** - https://www.un-igrac.org/sites/default/files/resources/files/Report_Groundwater%20Monitoring%20in%20SADC%20region.pdf;
- **SADC Country visit** - 2017.

Niger



Capital city: Niamey
Inhabitants: 22.4 Million

INSTITUTIONAL SETTING AND PURPOSE

The Ministry of Hydraulics and Sanitation is responsible for providing access to drinking water and sanitation. One of five sub-programs covers monitoring and protection of water resources.

The institution in charge groundwater resources is the Agency for Groundwater Exploitation (Office d'Exploitation des Eaux Souterraines), a public institution under the Ministry of Hydraulics and Sanitation.

CHARACTERISTICS OF THE NETWORK

Piezometric network of Niger is composed of 308 observation points, operated by the regional services of the Ministry of Hydraulics. Frequency of water level measurements is highly variable with 2-3 times per month to 1-2 per year.

PROCESSING AND DISSEMINATION

Two governmental databases store information on boreholes and hand dug wells: for the central region and for encompassing the whole country, although there is not much information from the north and east parts of the country.

The Ministry of Water (currently the Ministry of Hydraulics and Sanitation) has identified more than 24,000 wells and boreholes in the country, and a UNICEF study of 2010 compiled information of around 11,000 wells, many of them include info on water levels.

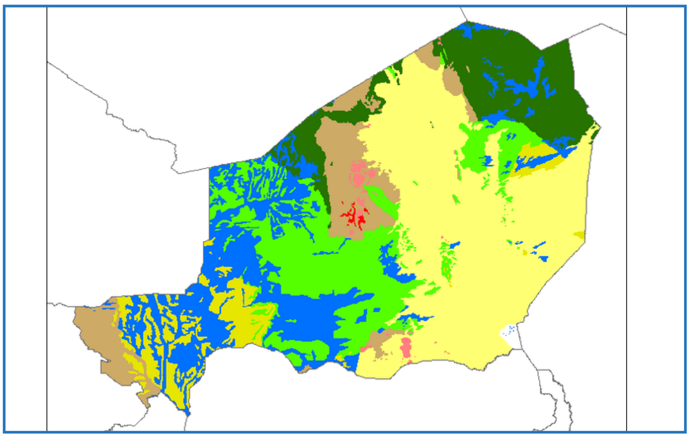


Fig. 58 - Geology map Niger, source: Earthwise.bgs.ac.uk

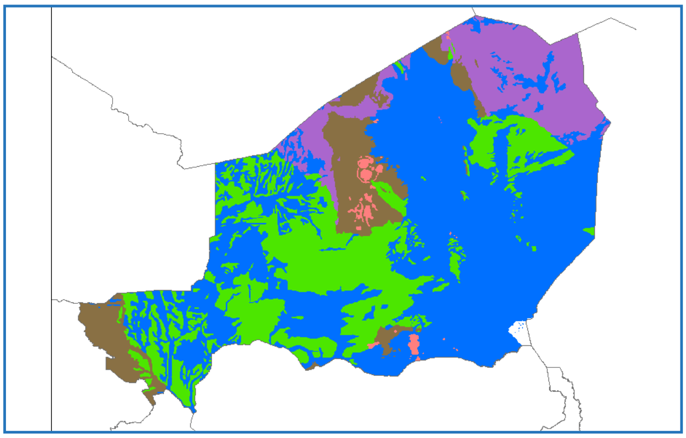


Fig. 59 - Hydrogeology map Niger, source: Earthwise.bgs.ac.uk

Sources

- **Ministry of Hydraulics and Sanitation** - http://www.hydraulique.gouv.ne/#;
- **Observatory of Sahara and Sahel (2011): Monitoring and Assessment of Transboundary Aquifers – Mali, Niger and Nigeria; Guyomard (2011)** - Concerted management of transboundary groundwater;
- **UNICEF. 2010** - Etude de faisabilité des forages manuels: identifiaction des zones potentiellement favorables. Republique du Niger Ministere de l'Eau, de l'Environnement et de la Lutte Contre Le Desertification; and
- **Upton, K., Ó Dochartaigh, B.É. and Bellwood-Howard, I. 2018. Africa Groundwater Atlas: Hydrogeology of Niger. British Geological Survey. Accessed 09-07-2019** - http://earthwise.bgs.ac.uk/index.php/Hydrogeology_of_Niger.

Nigeria

Capital city: Abuja
Inhabitants: 195.9 Million

INSTITUTIONAL SETTING AND PURPOSE

The Federal Ministry of Water Resources formulates the National Water Resources policies and coordinates their implementation. The Ministry is in charge of groundwater resources exploration and development. It also supports studies and research on surface and groundwater resources potential.

Nigeria Hydrological Services Agency (NIHSA) is an agency of the Federal Ministry of Water Resources that has the mandate of assessing the national water resources in terms of quantity, quality, availability and distribution in space and time. NIHSA is responsible for groundwater monitoring in Nigeria.

CHARACTERISTICS OF THE NETWORK

The network managed by NIHSA has 43 monitoring points, among them 32 are equipped with data loggers that measure the groundwater levels daily or twice a day.

PROCESSING AND DISSEMINATION

The data are stored at NIHSA headquarters in Abuja.

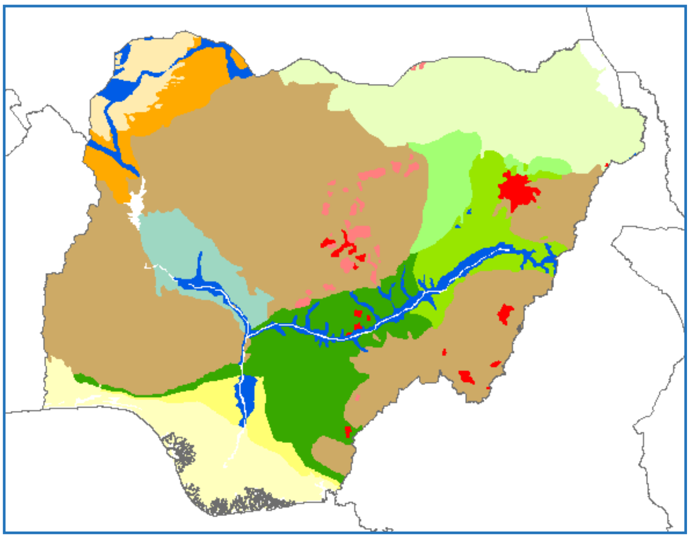


Fig. 60 - Geology map Nigeria, source: Earthwise.bgs.ac.uk

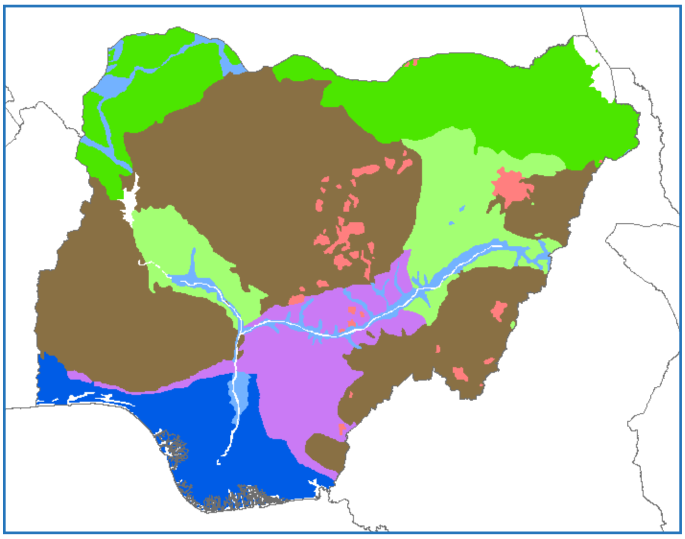
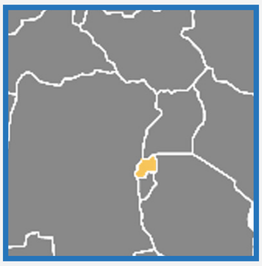


Fig. 61 - Hydrogeology map Nigeria, source: Earthwise.bgs.ac.uk

Sources

- **Observatory of Sahara and Sahel (2011): Monitoring and Assessment of Transboundary Aquifers – Mali, Niger and Nigeria; Guyomard (2011)** - Concerted management of transboundary groundwater;
- **Tijani, M., Crane, E., Upton, K., Ó Dochartaigh, B.É. and Bellwood-Howard,I. 2018. Africa Groundwater Atlas: Hydrogeology of Nigeria. British Geological Survey. Accessed 09-07-2019** - http://earthwise.bgs.ac.uk/index.php/Hydrogeology_of_Nigeria; and
- **Ministry Water Resources** - https://www.facts.ng/nigerian-ministries/ministry-water-resources.

Rwanda



Capital city: Kigali
Inhabitants: 12.3 Million

INSTITUTIONAL SETTING AND PURPOSE

The Rwanda Water Resources Board (RWB) is an institution in charge of implementing policies and strategies related to management of natural water resources, comprising monitoring and coordination among the sectors. The water resources monitoring programme of Rwanda, having a groundwater component, is designed to provide to stakeholders and decision makers with information to support the sustainable development and management of Rwanda's water resources, with particular attention to water productivity in agriculture and to adaptation to climate change.

CHARACTERISTICS OF THE NETWORK

In 2016, groundwater levels were recorded from twelve groundwater monitoring stations, including four piezometers where data were collected manually, and eight monitoring stations equipped with sensors (divers and barometers) recording data twice per day (at 6:00 and 18:00). The number of monitoring stations has been increasing with time, and currently, the monitoring network is composed by eight piezometers and thirteen groundwater monitoring stations equipped with sensors.

PROCESSING AND DISSEMINATION

The RWB produces an Annual Water Status Report which is an overview of key parameters and locations indicative of the overall state of Rwanda's water resources. The report is concise and meant for a broad public; It is divided into four sections: surface water quantity, groundwater quantity, water quality and water use. The RWB also maintains the Rwanda Water Portal, which is a web platform that stores and facilitates access to water resources related information such as water quality, surface water monitoring results, groundwater monitoring results, water laws and policies. Data are presented in various formats and with various levels of detail/accessibility, according to the type of user. The groundwater section of the portal contains a map with the location of 21 groundwater monitoring stations, and time-series of groundwater levels for the existing stations having data.

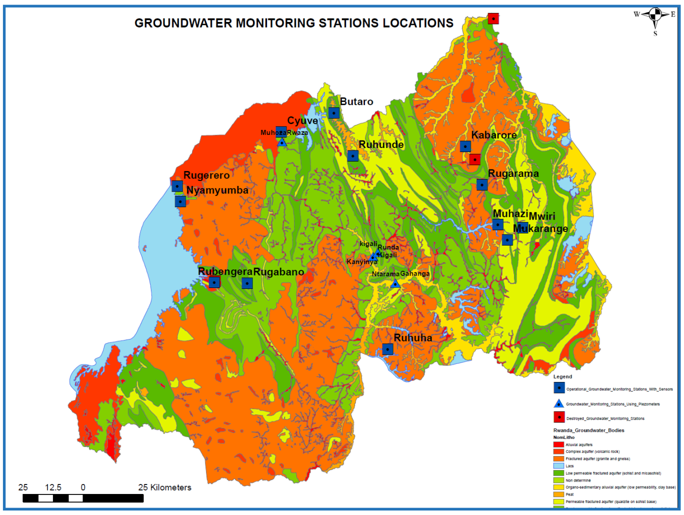


Fig. 62 - Groundwater Monitoring stations of Rwanda. Source: Rwanda Water Resources Board

Sources

- **Annual Water Status Report for 2016-2017, Rwanda Water and Forestry Authority (RWFA)** - https://waterportal.rwfa.rw/sites/default/files/2018-01/Annual%20Water%20Status%20Report.pdf;
- **Annual Water Status Report for 2019-2020, RWB** - https://waterportal.rwb.rw/sites/default/files/2018-01/Annual%20Water%20Status%20Report.pdf;
- **Feedback from the Rwanda Water Resource Board (RWB)** - received on 05-10-2020;
- **IGRAC. Information collected during the regional training programme on Integrating Groundwater Management within River Basins held from 15-17 January 2019 in Nairobi, Kenya** - https://www.un-igrac.org/news/integrating-groundwater-management-river-lake-basins-eastern-africa;
- **Rwanda Water Resources Board (RWB)** - http://rwb.rw/index.php?id=2;
- **Rwanda Water Resource Portal** - https://waterportal.rwb.rw/; and
- **Rwanda Water Resource Portal, Groundwater monitoring network** - https://waterportal.rwb.rw/data/ground_water.

Sierra Leone

Capital city: Freetown
Inhabitants: 7.7 Million

INSTITUTIONAL SETTING AND PURPOSE

The Ministry of Water Resources (MWR) of Sierra Leone is responsible for managing and protecting the water resources at local, national and transboundary levels.

The Sierra Leone Water Security Project was funded by the Department for International Development (DFID) of the United Kingdom through its national WASH facility and had the overall aim of 'putting in place the foundations for water security in Sierra Leone'. During this project, a groundwater monitoring network was installed, that measured groundwater levels from November 2012 onwards.

Currently, Sierra Leone does not have a national groundwater monitoring network.

CHARACTERISTICS OF THE NETWORK

The network was equipped with automatic data loggers with barometric sensors in hand-dug wells and deep wells. Water levels were measured manually at the beginning and end of the monitoring period to validate readings.

PROCESSING AND DISSEMINATION

The Salone Water Security portal, powered by the MWR, is the nation's focal point for national policies, strategies and regulation. It stores groundwater level data of the groundwater monitoring network of the Water Security Project (18 wells, available for download). Bumbuna Watershed Management Authority (BWMA) is in charge of data collection and storage.

The Salone portal also presents a map of 2014 with a proposed national groundwater monitoring network.

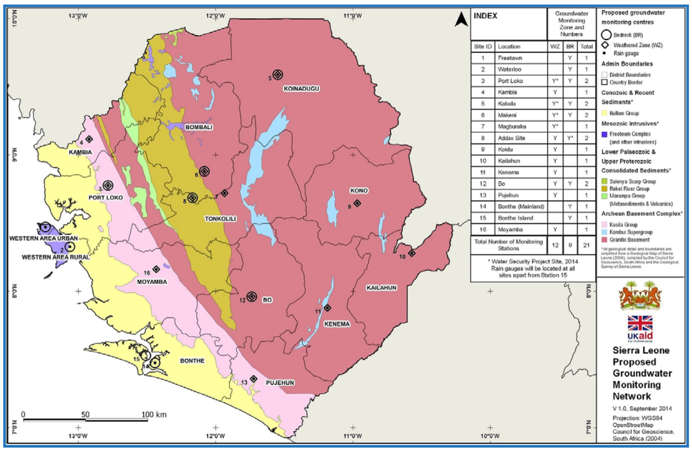


Fig. 63 - Proposed groundwater monitoring network, source: Salone Water Security

Sources

- **National Water Resources Management Agency Sierra Leone (Salone Water Security)** - https://www.salonewatersecurity.com;
- **Republic of Sierra Leone, Ministry of Water Resources. Water resources monitoring in Sierra Leone** - Vol 1 & 2. March 2015; and
- **Upton K, Ó Dochartaigh BÉ, Thomas M and Bellwood-Howard, I. 2018. Africa Groundwater Atlas: Hydrogeology of Sierra Leone. British Geological Survey. Accessed 09-07-2019** - http://earthwise.bgs.ac.uk/index.php/Hydrogeology_of_Sierra_Leone.

Somalia

Capital city: Mogadishu
Inhabitants: 15 Million

INSTITUTIONAL SETTING AND PURPOSE

The Ministry of Water Resources in Mogadishu, the Ministry of Water Resources in Somaliland and the Puntland State Agency for Water, Energy and Natural Resources are institutions related to groundwater resources management in Somalia.

In Somalia there is no national groundwater monitoring network taking place. However, in 2012, FAO/SWALIM (Somalia Water and Land Information Management) established a groundwater monitoring network in the provinces of Somaliland and Puntland.

CHARACTERISTICS OF THE NETWORK

The network is equipped with automatic water level data loggers. Currently, 4 monitoring stations are installed in Somaliland (Hargeisa, Borama, Berbera and Burco) and 4 in Puntland (Garoowe, Boosaaso, Gaalkacyo and Qardho).

PROCESSING AND DISSEMINATION

The Live-Map in the SWALIM portal shows the status of water resources in Somalia, including information about boreholes and water points, figure 64.

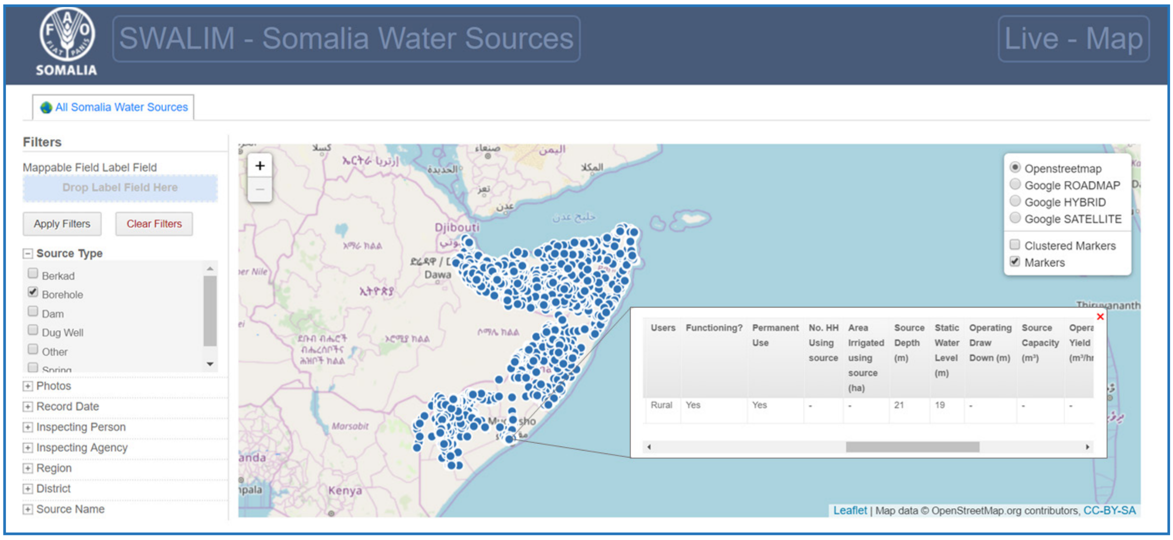
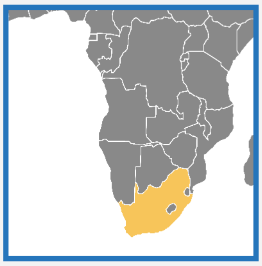


Fig. 64 - Live-Map SWALIM

Sources

- **IGRAC (2012). Information collected during GGMN Workshop in the IGAD Region** - https://www.un-igrac.org/news/groundwater-monitoring-network-programme-africa;
- **Gadain H, Stevanovic Z, Upton K. Ó Dochartaigh BÉ and Bellwood-Howard, I. 2018. Africa Groundwater Atlas: Hydrogeology of Somalia. British Geological Survey. Accessed 09-07-2019** - http://earthwise.bgs.ac.uk/index.php/Hydrogeology_of_Somalia;
- **Somalia Water and Land Information Management (SWALIM)** - https://www.faoswalim.org/water/water-resources/ground-water; and
- **SWALIM – Somalia Water Sources – Live Map** - http://fmt.faoso.net/imms/fmt/maps/website/227.



South Africa (RSA)

Capital city: Cape Town (legislative) / Pretoria (administrative) / Bloemfontein (judicial)
Inhabitants: 57.8 Million

INSTITUTIONAL SETTING AND PURPOSE

The institution in charge of groundwater management in Republic of South Africa (RSA) is the Department of Water Affairs and Forestry (DWA). The DWA has delegated most of the monitoring tasks to its regional offices. Regional offices are set up in all the provinces of RSA, but some of them lack capacity to complete all the delegated tasks.

The objectives of the groundwater monitoring plan are to identify spatial and temporal trends, and to understand the causes and effects of groundwater changes in affected areas. The plan includes the monitoring of groundwater levels and its quality.

CHARACTERISTICS OF THE NETWORK

Groundwater levels are monitored monthly at approximately 1,800 monitoring points. Piezometric levels are measured manually with water level dippers. The Department of Water and Sanitation (DWS) makes use of (detailed) field forms developed by an in-house Groundwater Field Monitoring Committee.

Standard operation procedures (SOP) are applied as a data quality control to ensure proper data collection. Two main procedures are: standard for Geosite description, and standards for capturing groundwater data.

PROCESSING AND DISSEMINATION

DWS produces annual Groundwater Level Maps, figure 65. Currently three maps are available on the website of the DWS indicating the difference of groundwater levels between Septembers of 2017 to 2018, of 2018 to 2019 and of 2017 to 2019.

Data are stored in the National Groundwater Archive (NGA), which is a centralized database with a web interface. Everyone with an interest in groundwater can register to search, capture and store data. Only one value of water level per month is stored in the NGA; larger time-series are stored separately in a Hydstra database.

The databases can be accessed from inside and outside the department and are accessible for registered users. However, not all data are online and detailed water level time series must be requested.

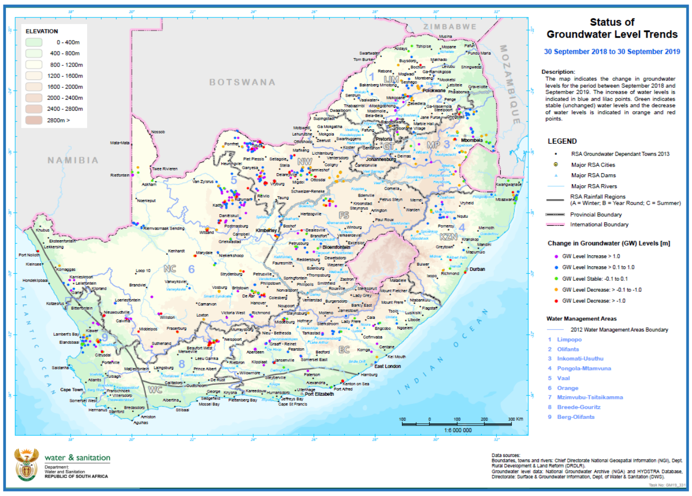


Fig. 65 - Difference in groundwater levels September 2018 to September 2019. Source: DWA

Sources

- **Department of Water and Sanitation (DWS). Groundwater level maps 2017-2019** - http://www.dwa.gov.za/Groundwater/maps/gwlevelmaps.aspx;
- **DWS. The National Groundwater Archive (NGA)** - http://www.dwa.gov.za/groundwater/nga.aspx;
- **Feedback from the Department of Water Affairs and Forestry** - received on 05-10-2020;
- **IGRAC, 2013. Groundwater Monitoring in the SADC Region, 2013. Overview prepared for the Stockholm World Water Week** - https://www.un-igrac.org/sites/default/files/resources/files/Report_Groundwater%20Monitoring%20in%20SADC%20region.pdf; and
- **SADC Country visits** - 2017.

Sudan

Capital city: Khartoum
Inhabitants: 41.8 Million

INSTITUTIONAL SETTING AND PURPOSE

Several governmental institutions are responsible for groundwater in Sudan:

- The Ministry of Irrigation and Water Resources, responsible for all water resources, irrigation and domestic water supply;
- The Groundwater and Wadis Department, responsible for groundwater assessment, development and management; and
- State corporations (18 in total), responsible for rural and urban water supply (drinking water).

Monitoring networks for groundwater exist at regional and national scales but may be not covering all aquifers.

A regional network exists within the transboundary network of the Nubian Sandstone Aquifer System, which is monitored by the other three countries sharing the aquifer (Egypt-Libya-Chad) as well. Data collected is stored in a regional database named NARIS (Oracle), which is shared online among the four countries, with the server located in Tripoli, Libya. Eight monitoring wells are part of the network.

The Groundwater and Wadis Department monitors groundwater levels in the wadis Nyala and Gash and the Nubian Sandstone aquifer in the north of the country. Monitoring is carried out both manually and automatically. Telemetry technology was introduced in 11 wells in the Nubian Aquifer network and it is planned to use this technology in some other aquifers.

CHARACTERISTICS OF THE NETWORK

Monitoring data are stored in digital form in the Groundwater Directorate Database and in spreadsheets. Unpublished reports with results from groundwater quality monitoring are available at the ministries.

Fig. 66 - Water tap in Sudan, by: Vitor Martinho

Sources

- **Feedback from Secretary of Transboundary Groundwater Aquifers, Ministry of Irrigation and Water Resources of Sudan** - received on 17-09-20;
- **Gadelmula AH, Upton K, Ó Dochartaigh BÉ and Bellwood-Howard, I. 2018. Africa Groundwater Atlas: Hydrogeology of Sudan. British Geological Survey. Accessed 09-07-2019** - http://earthwise.bgs.ac.uk/index.php/Hydrogeology_of_Sudan;
- **IGRAC (2012). Information collected during GGMN Workshop in the IGAD Region** - https://www.un-igrac.org/news/groundwater-monitoring-network-programme-africa; and
- **IGRAC. Information collected during the regional training programme on Integrating Groundwater Management within River Basins held from 15-17 January 2019 in Nairobi, Kenya** - https://www.un-igrac.org/news/integrating-groundwater-management-river-lake-basins-eastern-africa.

Tanzania

Capital city: Dodoma
Inhabitants: 56.3 Million

INSTITUTIONAL SETTING AND PURPOSE

Water resources in Tanzania are managed basin-wise; five river basins and four lake basins. Water monitoring is done by the Ministry of Water.

There is no national groundwater monitoring programme in Tanzania, but groundwater levels are monitored in several areas of the country.

CHARACTERISTICS OF THE NETWORK

Groundwater monitoring in Tanzania started in 1955 with the Makutapora well field. In the early 2000, 12 monitoring wells were drilled in Rufiji basin with the assistance of the World Bank. In 2007, 30 boreholes were added in the Internal Drainage Basin, and 15 out of 35 planned boreholes were installed in the Pangani River Basin in 2010. 19 boreholes were drilled and installed with water level loggers by Japan International Cooperation Agency in Wami Ruvu Basin in 2011.

Currently, groundwater level monitoring is carried out in the Makutapora Basin in the Dodoma region by ten automatic data loggers, and in Arusha by the Arusha Urban Water Supply Authority and in TPC-Moshi. In Arusha groundwater levels are measured manually on a daily basis.

In 2017, a local groundwater monitoring network was installed in the Upper Great Ruaha Basin Observatory in southern highlands of Tanzania by the GroFutures team at Sokoine University of Agriculture (SUA, Tanzania).

Fig. 67 - The Ruaha Basin in Tanzania

Sources

- **IGRAC, 2013. Groundwater Monitoring in the SADC Region, 2013. Overview prepared for the Stockholm World Water Week** - https://www.un-igrac.org/sites/default/files/resources/files/Report_Groundwater%20Monitoring%20in%20SADC%20region.pdf;
- **IGRAC. Information collected during the regional training programme on Integrating Groundwater Management within River Basins held from 15-17 January 2019 in Nairobi, Kenya** - https://www.un-igrac.org/news/integrating-groundwater-management-river-lake-basins-eastern-africa;
- **GroFutures, 2017. Groundwater monitoring established in the upper great Ruaha Basin of Tanzania** - http://grofutures.org/article/groundwater-monitoring-established-in-the-upper-great-ruaha-basin-of-tanzania; and
- **Sangea H, Upton K, Ó Dochartaigh BÉ and Bellwood-Howard, I. 2018. Africa Groundwater Atlas: Hydrogeology of Tanzania. British Geological Survey. Accessed 09-07-2019** - http://earthwise.bgs.ac.uk/index.php/Hydrogeology_of_Tanzania.

The Gambia

Capital city: Banjul
Inhabitants: 2.3 Million

INSTITUTIONAL SETTING AND PURPOSE

The Department of Water Resources (DWR) under the Ministry of Fisheries, Water Resources and National Assembly Matters is in charge of the development, use and protection of groundwater in the Gambia. The DWR maintains the national groundwater monitoring network. The network was established within the National Water Sector Reform Project (NWSRP) funded by the African Development Bank (AfDB) through the African Water Facility (AWF) from 2011 to 2015. The project aimed to modernize the groundwater monitoring network to enhance the assessment of resources for sustainable groundwater management and development. However, due to high failure of the current groundwater data loggers, the department is also anticipating for further support from Climate Smart Rural WASH Development Project (CSRWASHDEP) with funding AfDB, to increase the number of monitoring sites and purchase more stable automatic data loggers.

CHARACTERISTICS OF THE NETWORK

The Department presently operates a network of about 38 groundwater monitoring boreholes, installed with automatic data loggers, which are currently monitored manually. Around half of the monitoring points are spread in the Greater Banjul Area (GBA), the rest are equally distributed eastward at 35km distance throughout the north and south bank of the country. The loggers are designed to measure water level below ground surface (to be subsequently referenced to mean sea level) and groundwater temperature etc. The groundwater measuring devices were set at 6 hours interval, but the data was downloaded at a monthly basis or less frequently.

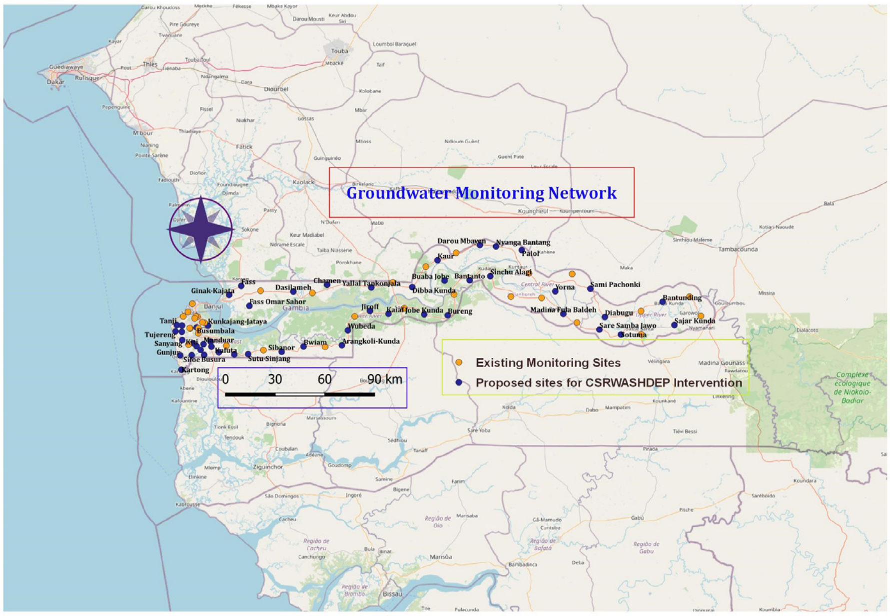


Fig. 68 - Groundwater monitoring network of The Gambia

Sources

- **Bibliographic reference: Bojang L, Corr G, Upton K, Ó Dochartaigh BÉ and Bellwood-Howard, I. 2018. Africa Groundwater Atlas: Hydrogeology of the Gambia. British Geological Survey. Accessed 02-07-2019** - http://earthwise.bgs.ac.uk/index.php/Hydrogeology_of_Gambia;
- **Feedback from the Department of Water Resources, Ministry of Fisheries, Water Resources and National Assembly Matters of The Gambia** - received on 22-09-20; and
- **GGMN People Network**.

Tunisia

Capital city: Tunis
Inhabitants: 11.6 Million

INSTITUTIONAL SETTING AND PURPOSE

The General Directorate of Water Resources (DGRE) and the National Water Distribution Utility (SONEDE) are the key institutions in Tunisia involved in groundwater management.

CHARACTERISTICS OF THE NETWORK

Monitoring of groundwater levels is done twice a year by 24 departments of the DGRE, through a network of more than 2,000 shallow wells and more than 1,100 deep wells.

PROCESSING AND DISSEMINATION

DGRE publishes an annual report with the results of the monitoring of the deep aquifers, and every 5 years a report with the results of the monitoring of the shallow aquifers.

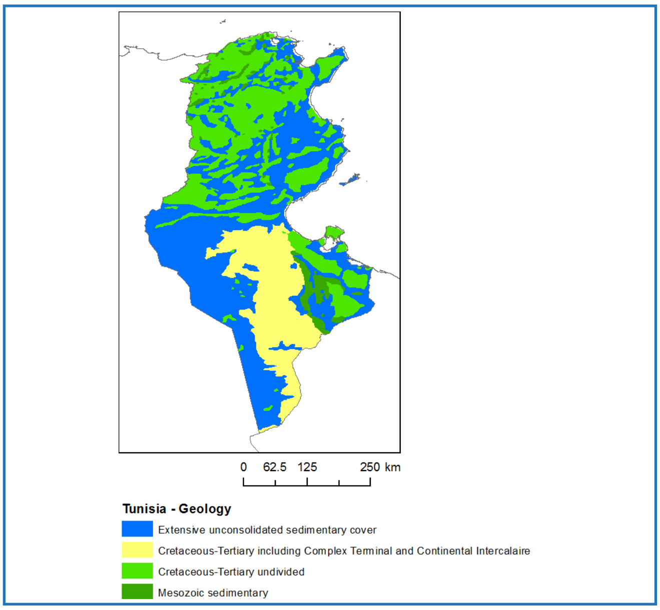


Fig. 69 - Geology map Tunisia, source: Earthwise.bgs.ac.uk

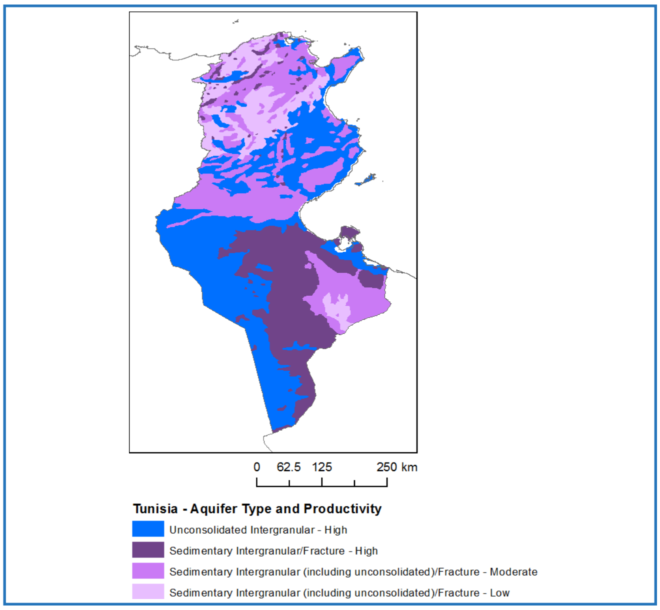


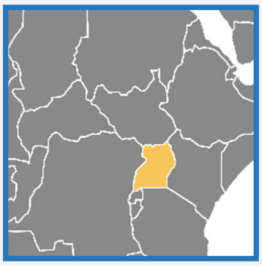
Fig. 70 - Hydrogeology map Tunisia, source: Earthwise.bgs.ac.uk

Sources

- **Ben Ammar, S., Mekni, A., Upton, K., Ó Dochartaigh, B.É. and Bellwood-Howard, I. 2018. Africa Groundwater Atlas: Hydrogeology of Tunisia. British Geological Survey. Accessed 09-07-2019** - http://earthwise.bgs.ac.uk/index.php/Hydrogeology_of_Tunisia;
- **IWMI & USAID 2017. Groundwater Governance in Tunisia – A Policy White Paper. Groundwater Governance in the Arab World – Taking Stock and addressing the challenges** - https://publications.iwmi.org/pdf/H048394.pdf;
- **Ministry of Agriculture, Hydraulic Resources and Fisheries. Water resources** - http://www.agridata.tn/fr/group/pluviometrie; and
- **Euro-Mediterranean Information System on know-how in the Water Sector** - http://www.semide.net/fr.

Uganda

Capital city: Kampala
Inhabitants: 42.7 Million



INSTITUTIONAL SETTING AND PURPOSE

The Directorate of Water Development and the Directorate of Water Resources Management (DWRM), both under the Ministry of Water and Environment (MWE), are responsible for implementing national legislation on the sustainable use of natural resources, including groundwater. Among others, DWRM is in charge of managing and monitoring groundwater resources.

CHARACTERISTICS OF THE NETWORK

In 2017, the national groundwater monitoring network consisted of 55 boreholes, from which 23 were operational and 23 were newly drilled and waiting for instrumentation. Some of the monitoring wells are located close to abstractions boreholes to monitor the effects of abstraction, but most of them are far to monitor natural groundwater level fluctuations.

PROCESSING AND DISSEMINATION

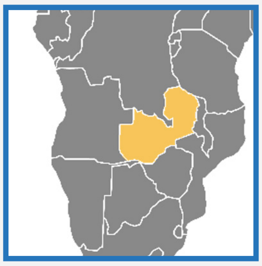
Groundwater monitoring started in 1998 and recordings of groundwater levels are available for 30 stations. The National Groundwater Database (NGWDB) managed by the DWRM contains key borehole information provided by drilling contractors, as they must return borehole completion forms quarterly to DWRM for each borehole drilled. Only boreholes deeper than 30 m are generally included in the database. The national monitoring database is Access-based but not user-friendly.

Groundwater maps and the report, results of the Mapping Groundwater Resources in Uganda Programme 2012, are publicly available. They present the location of shallow, deep boreholes and springs.

Fig. 71 - A water well in Uganda, by: Dennis Wegewijs

Sources

- **GGMN workshop IGAD** - 2012;
- **Ministry of Water and Environment. Directorate of Water Resources Management. Kibaale District Groundwater Report, 2012. Mapping of Groundwater Resources in Uganda** - https://www.mwe.go.ug/sites/default/files/library/Kibaale%20Ground%20Water%20Map%20Report.pdf; and
- **Ministry of Water and Environment, Republic of Uganda. Kibaale Groundwater Maps** - https://www.mwe.go.ug/library/kibaale-ground-water-maps-0.



Zambia

Capital city: Lusaka
Inhabitants: 17.4 Million

INSTITUTIONAL SETTING AND PURPOSE

The Department of Water Resources Development (DWRD) under the Ministry of Water Development, Sanitation and Environmental Protection is responsible for the water policy, transboundary groundwater resources management and development. DWRD is also in charge of aquifer mapping, well field development and groundwater exploration. The Water Resources Management Authority (WARMA), which is an autonomous body established by the Water Resources Management Act, is responsible for the implementation of the Act, the allocation and management of all water resources of Zambia, including groundwater monitoring.

Only a part of monitoring is carried out by the institutions mandated to do so because of budget limitations. Groundwater monitoring is partly performed by organizations and industries within their areas of operations such as the Zambezi River Authority (Lake Kariba and parts of the Zambezi River), Zambia Electricity Supply Cooperation (on Kafue River) and various mining companies. Some of these monitoring data are reported monthly to WARMA.

CHARACTERISTICS OF THE NETWORK

The central groundwater monitoring network consists of 100 piezometers, of which 44 are located around Lusaka, where groundwater levels are monitored 4 times per year.

PROCESSING AND DISSEMINATION

The Ground Water Management Information System (GRIMS) is used to store and analyse data and produce information. GeoDin is another software used at WARMA. The data are available to the WARMA and the Ministry, and external users can access it upon written request. Data from 1970 onwards are present in the files.

The main users of the data are the WARMA, the Ministry, universities and consultants.

Fig. 72 - Bird eye view of the Victoria falls waterfall on Zambezi river

Sources

- **GGMN workshop SADC** - 2013; and
- **Country visits SADC** - 2017.

Zimbabwe

Capital city: Harare
Inhabitants: 14.4 Million

INSTITUTIONAL SETTING AND PURPOSE

The Groundwater Division of the Zimbabwe National Water Authority (ZINWA) is a parastatal entity under the Ministry of Lands, Agriculture, Water and Rural Resettlement. ZINWA is responsible for monitoring groundwater quality and levels. Furthermore, the Catchment Councils, through the sub-catchment councils, are responsible for water allocation and groundwater monitoring in the context of a catchment scale.

There is no national groundwater monitoring plan in Zimbabwe, but groundwater levels are measured by ZINWA in three major aquifers: the Lomagundi Dolomite Aquifer (in the north west of Zimbabwe), the Nyamadlovu Sandstone Aquifer (in the south west of Zimbabwe) and the Save Alluvial Aquifer (in the south east of Zimbabwe). The objective is to perform resource monitoring for the development of well fields.

CHARACTERISTICS OF THE NETWORK

Water levels are measured manually once per month. There are routine checks to assure the quality of the data, but no standard protocol is employed. During data collection, no specific procedures for quality control are applied.

Considering the number of authorities collecting various groundwater data, it is expected that quality control procedures or protocols vary depending on the type of data being collected.

PROCESSING AND DISSEMINATION

For the well fields, the monitored groundwater level data are stored in Excel files in internal hard drives, and in some external drives for backing up. Hard copies of field measurements are also stored. The data can be accessed through a formal written request indicating the purpose of the data.

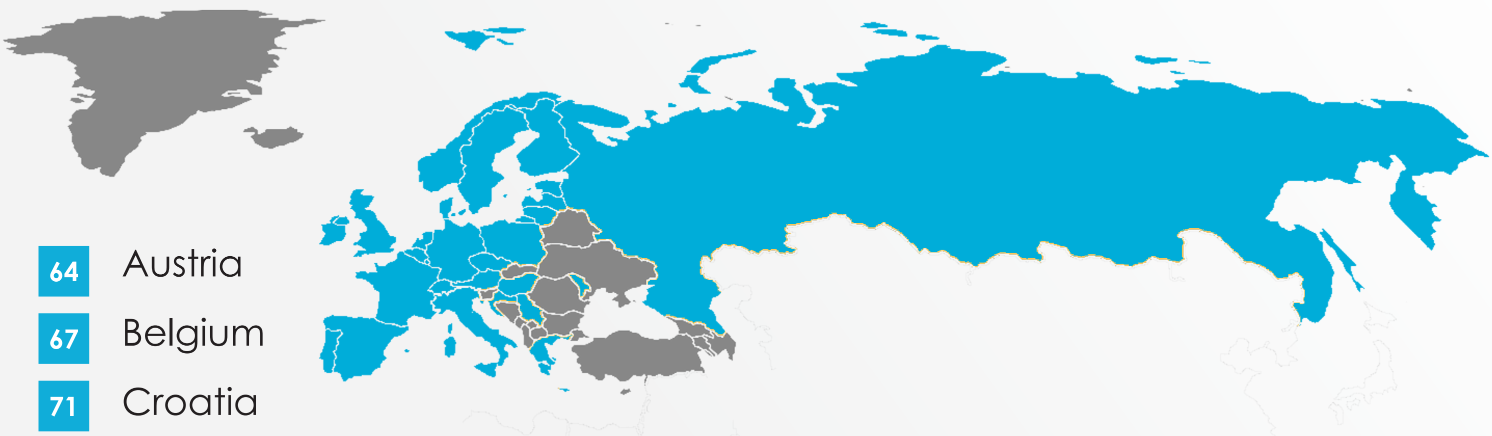
The external access to the data can be challenging since there is no national database. This means that the data are found in different departments or stakeholders, which must be approached separately to make a request. Moreover, in most cases it is not possible to know beforehand what kind of data are available and in which department.

Fig. 73 - Aerial view of cultivated fields in the countryside of Zimbabwe-by Soldo76

Sources

- **Country visits SADC** - 2017;
- **Feedback from the Department of Water Resources Planning and Management; Ministry of Lands, Agriculture, Water and Rural Resettlement** - received on 22-09-20; and
- **GGMN workshop SADC** - 2013.

EUROPE & CAUCASUS



Austria

Capital city: Vienna
Inhabitants: 9 Million

INSTITUTIONAL SETTING AND PURPOSE

The Sub department Water Balance (Wasserhaushalt – Hydrographisches Zentralbüro) belonging to the Department of Water Management in the Federal Ministry for Agriculture, Regions and Tourism (BMLRT) coordinates the data collection, quality control, evaluation and publication of hydrographic information, including groundwater.

* Note that from January 8, 2018 to January 28, 2020 the Ministry was called Federal Ministry for Sustainability and Tourism (BMNT). Before 2018, it was called Federal Ministry of Agriculture, Forestry, Environment and Water Management (BMLFUW). Older publications refer to BMLFUW or BMNT as the institution in charge of groundwater monitoring in Austria.

CHARACTERISTICS OF THE NETWORK

Since 1893, the results of the observations of quantitative monitoring have been summarized in the Hydrographic Yearbook of Austria, which includes a chapter dedicated to the status of pore groundwater since 1948 and a chapter with hydrologic properties of springs to characterise joint and karst aquifers since 1995. According to the Yearbook 2016, the observation network of the Hydrological service has a national coverage of around 83,850 km2, and comprises 3535 groundwater level measuring points, 1518 groundwater temperature measuring points and 91 springs. Groundwater levels are collected either weekly (41% of the measuring-sites) or continuously in 15minutes to 1hour-intervals, and groundwater temperature is collected in the same way, the percentage of continuous sites about 89%. At springs all parameters (water level/discharge, water temperature and electrical conductivity referred to 25 °C) are measured every 15 minutes.

There also exits a soil-water-monitoring network in Austria partly since 1995. In open-land-sites values of water-content, soil-moisture-tension and soil-water-temperature are collected continuously in 4 to 7 depths from 5 to 160 cm underground. In lysimeters infiltration water is collected in buckets and measured continuously or weekly. Since 2019 there are special sites to monitor the surface-water-content. These data are not published yet.

The web-GIS-platform eHYD – hydrological data in the internet shows the location and the ID of all monitoring points with published data on the map "monitoring points and data" (Messstellen und Daten), figure 74.

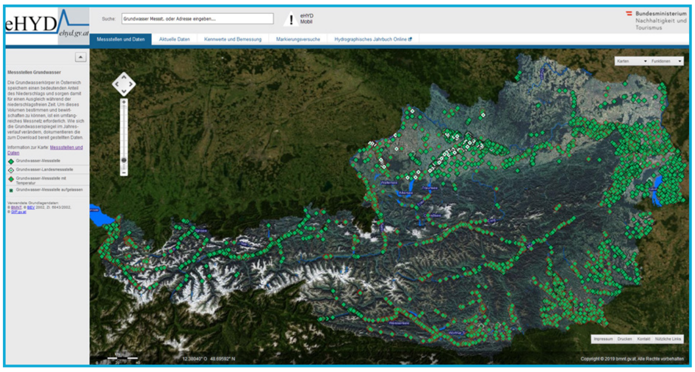


Fig. 74 – eHYD platform. Map: monitoring points and data (Messstellen und Daten) - groundwater monitoring points

PROCESSING

Until 2012 the Hydrographic Yearbook auf Austria was printed and contained a short description of the hydrological processes in the respective year and a large number of tables with measured values and statistics. From 2013 the tables are only published online, and the printed part of the Hydrographic Yearbooks of Austria contains a detailed description and analysis of the hydrological conditions during the year. To assess the status of the groundwater resources in Austria three different methods are used.

The first method compares the annual average with the mean of a selected historical record. In the case of 2016, for each monitoring point, the annual average value for 2016 was compared with the mean for the period 1981-2010. Only monitoring points with values from 1981 to 2016 were included, figure 75.

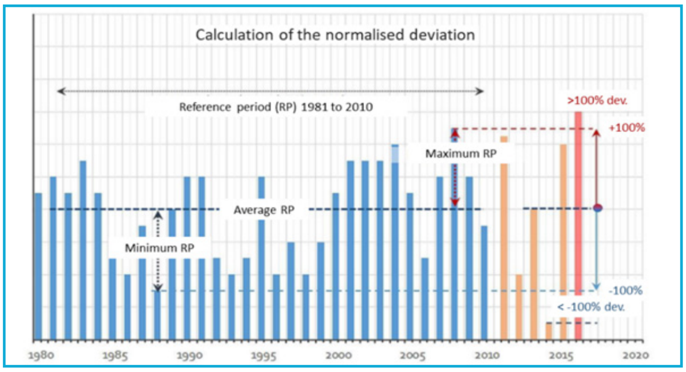


Fig. 75 – Calculation method for normalised deviation

Annual averages greater than 100% or less than -100% for the period 1981-2010 are considered as values that have never occurred before or during the comparison period. Values between -100% and 100% correspond to the variances observed in the comparative period.

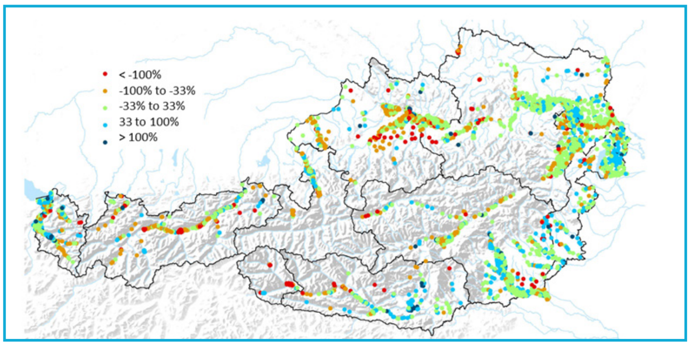


Fig. 76 – Deviation of the average groundwater level for the year 2016 from the reference period 1981-2010 as a percentage of the maximum or minimum values in the reference period 1981-2010

The second method is an analysis of seasonal change, based on comparison of daily groundwater level mean values at selected monitoring points with their long-term daily mean, minimum and maximum, figure 76. The same is done for springs.

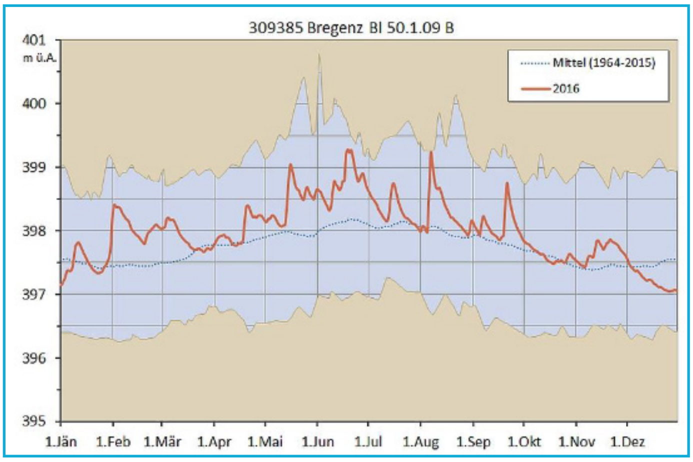


Fig. 77 – Daily average groundwater level of 2016 for a single monitoring point in Bregenz, compared to long term daily mean, minimum and maximum. Source: Hydrographic Yearbook of 2016

The third method is used to estimate the volume of water recharged or discharged from a catchment area. During the year, the groundwater volume fluctuations in each catchment area are calculated daily and presented in hydrographs, figure 78. Each catchment area is composed of several groundwater areas.

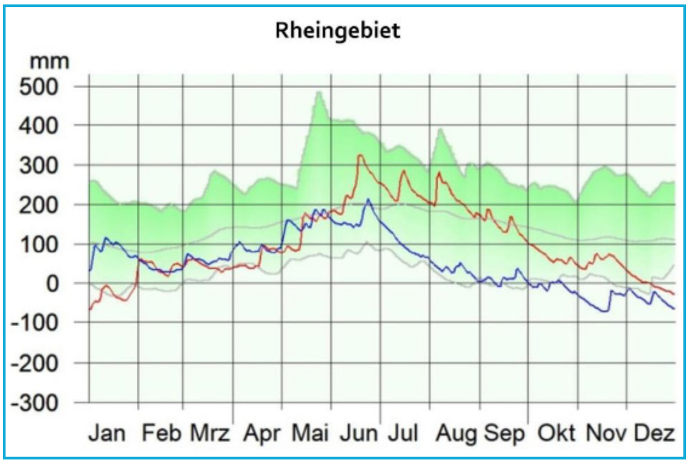


Fig 78 – Changes in groundwater volume (VOLPA VOLume Per Area within 1 year (blue: hydrograph in 2015, red: 2016) in Rhein River Basin. The green area indicates the range of fluctuation between the daily minimum and daily maximum since 1990. Source: Hydrographic Yearbook of 2016

Starting from 1 January 1990 until the end of 2015, groundwater levels (contour lines) for each groundwater area were constructed for each day using Kriging, and the volume change was calculated considering the average porosity per each groundwater area.

These changes were summed up within all catchment areas covered by groundwater monitoring stations and displayed in mm per area. The porosity values were derived from data from the Geological Survey, by assigning average porosities to the lithological units (from 7 to 25%). All catchment areas are shown in figure 79.

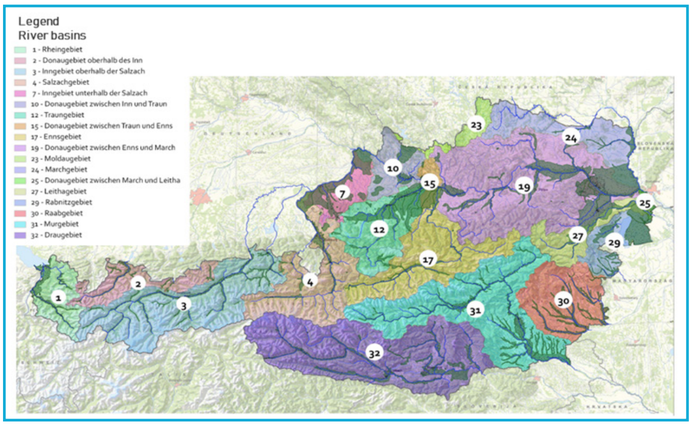


Fig. 79 – Overview of the river basins after the WKEV (Water Cycle Survey Regulation) and the groundwater areas. Source: Hydrographic Yearbook of 2016

DISSEMINATION

Hydrographic Yearbooks of Austria beginning with 2004 are downloadable as PDF from the web page of BMLRT under the menu "Service" -> "Publications" or https://www.bmlrt.gv.at/wasser/wasser-oesterreich/wasserkreislauf/hydrographische_daten/jahrbuecher.html. Older printed Yearbooks can be asked for at the subdepartment Water Balance (wasserhaushalt@bmlrt.gv.at).

Since 2014 tables and evaluations in PDF-format are to be download separately from the web-application Hydrographic Yearbook online at https://wasser.umweltbundesamt.at/hydjb/. This application is part of the Water Information System Austria (WISA), which is a central platform to access data and information about the Austrian water sector. There are tables with monthly mean values, the annual mean, maximum and minimum of the year of groundwater level and groundwater temperature for every monitoring point grouped by river basin and groundwater basin. They are to be find under the menu "Download evaluations" (Auswertungen herunterladen) -> "River basins" (Flussgebiete).

Erstelldatum: 14.Mrz.2019 Hydrographisches Jahrbuch 2016 GWS 1

Monats- und Jahresmittel der Grundwasserstände mit Extremwerten (Hauptwerte)

- Grundwasserstände m ü.A. -

Nr.	Messstelle Messpunkt m ü.A. Beobachtungsbeginn	m ü.G. Daten verwendet ab	EDV-Mess-stellen-nummer beeinflusst / artesisch/gespannt	Messgerät	I VII	II VIII	III IX	IV X	V XI	VI XII	Jahr	im Berichtsjahr m ü.A.	Datum	vor dem Berichtsjahr m ü.A.	Datum
	RHEINGEBIET – Leiblachtal														
1	Hörbranz, Bl 40.1.04 418.36 1983	- 0.17	327700	D	404.20 405.38	404.80 405.16	404.83 404.64	404.33 404.21	405.22 404.37	405.82 403.99	404.74	403.58 406.79	04.01. 21.06.	402.49 408.87	07.01.1986 03.06.2013
2	Hörbranz, Bl 40.1.05 437.90 1983	0.73	327718	D	408.53 410.04	408.80 409.89	409.08 409.63	408.94 409.28	409.05 409.01	409.65 408.92	409.24	408.47 410.13	08.01. 02.07.	407.93 411.31	27.05.1991 18.11.2002
3	Hörbranz, Bl 40.1.06 410.55 1983	0.85	327726	D	405.18 405.45	405.47 405.42	405.42 405.18	405.15 404.97	405.51 405.20	405.78 404.94	405.31	404.76 406.24	31.12. 20.06.	403.67 407.49	28.10.1985 02.06.2013
4	Hörbranz, Bl 40.1.07 A 430.51 1994	0.90 03.12.2001	327767 1	D	417.11 418.30	417.35 418.32	417.65 418.18	417.63 417.94	417.78 417.80	418.11 417.66	417.82	417.00 418.38	08.01. 23.08.	415.91 418.42	05.10.2003 25.01.2011
5	Hörbranz, Bl 40.1.08 428.15 1984	1.09	327742	D	425.45 425.37	425.49 425.46	425.34 425.33	425.31 425.08	425.53 425.37	425.60 424.99	425.36	424.91 425.92 Ö	26.12. 13.05.	424.51 426.59	25.02.2008 01.07.1991
6	Hörbranz, Bl 40.1.09 A 468.87 1998	0.92 03.12.2001	327775 1	D	462.87 462.68	463.20 462.93	462.71 462.63	462.51 462.14	462.92 462.60	463.18 461.78	462.68	461.47 464.29	31.12. 01.02.	460.66 465.89	16.08.2004 02.06.2013
7	Lochau, Bl 40.1.02 399.03 1983	0.75	327684	D	396.60 396.85	396.67 396.73	396.59 396.58	396.56 396.46	396.72 396.55	396.97 396.46	396.64	396.41 397.28	17.10. 19.06.	394.01 397.64 396.64	08.02.1993 24.05.1999 06.09.2012
8	Lochau, Bl 40.1.03 416.73 1983	0.82	327692	D	405.60 406.86	406.35 406.73	406.27 406.17	405.82 405.56	406.87 405.96	407.41 405.05	406.22	404.73 408.26	31.12. 20.06.	403.53 410.09	30.10.1995 02.06.2013

Table 3 – Table with monthly means, annual means, maxima and minima 2016 of groundwater level in the groundwater bain Leiblachtal in Rhein River Basin

For each observed spring a PDF with daily discharge means, monthly and annual means and extrema for all measured parameters (discharge, water temperature, electrical conductivity and in special cases turbidity) and hydrographs is downloadable under the menu “Download evaluations” (Auswertungen herunterladen) -> “Monitoring points” (Messstellen). The springs theirs PDFs wanted to be downloaded can be selected from a list or a map, figure 80.

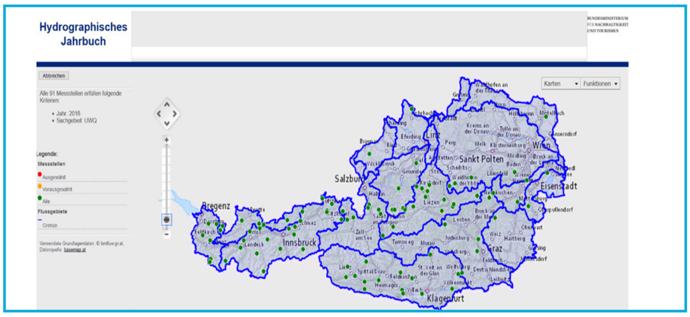


Fig. 80 – Hydrographic yearbook online. Map with observed springs and borders of the river basins 2016

In order to give interested people access not only to PDF-Tables with values of one year, but also to long-term data in a format to be used further 2005 the web-GIS-platform eHYD went online. There, on the first register “Monitoring points and data” (Messstellen und Daten), data from the hydrographic archive can be downloaded. All measuring points published in the yearbook are displayed in position either all together on one map or divided into the subject areas precipitation, surface water, groundwater (figure 74) and springs. Clicking on the symbol of a measuring point opens a tooltip with links for downloading the verified data available at this measuring point in CSV format. The data range from the beginning of electronic availability to the last year published in the form of the Hydrographic Yearbook. For groundwater there are downloadable monthly means as well as annual maxima and minima of groundwater level and groundwater temperature. For springs there are downloadable daily means of discharge, water temperature and electrical conductivity. On the second tab of eHYD, current unchecked values for runoff, groundwater and precipitation of stations equipped with remote data transmission are displayed on separated maps. In order to give a quick overview of the current situation, the colour of the measuring point symbols indicates the current status such as low, medium or high. The classification for groundwater and so the colouring of the symbols is done similar to the first method used in the yearbook for describing groundwater status. The deviation of the current groundwater level from the mean groundwater level of the reference period is converted to a percentage of the maximum overrun or underrun that occurred during the reference period at that day. There are five categories and colours, figure 81. Green colour presents a current value that is accepted as average and lays between -25 and 25%. Values with a deviation between 25 and 100%, or -25 and -100% are classified as high or low groundwater levels (blue and orange respectively). Values with a positive or negative deviation of more than 100% are classified as very high or very low (purple and red respectively) since they have never occurred in the reference period on the considered day.

Category	Deviation (%)	Symbol and Colour
Very high groundwater level	Higher than 100	purple rhombus
High groundwater level	25 to 100	blue rhombus
Middle groundwater level	-25 to 25	green rhombus
Lower groundwater level	-100 to -25	orange rhombus
Very low groundwater level	Lower than -100	red rhombus
No current data available		white rhombus

Fig. 81 – Classification of current groundwater levels in eHYD

A click on the symbol of a groundwater measuring point opens a pop-up-graph which shows the daily mean values of the last eleven months in comparison to the average, minimum and maximum value of each day for the selected groundwater station, figure 82, similar to the second method used in the Hydrographic Yearbook. The data are often displayed with one or two days of delay due to polling intervals and the calculation of the daily means.

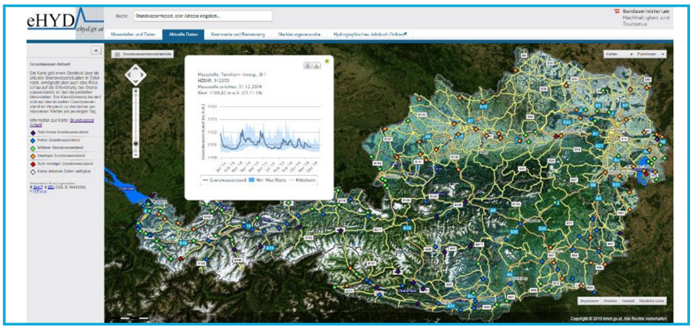


Fig. 82 – eHYD platform. Map: Current groundwater levels (Grundwasser Aktuell)

Sources

- **BMLFUW changes to BMNT** - https://www.eea.europa.eu/publications/92-9167-032-4/page003.html;
- **Feedback from BMLRT** - received on 31-01-2020;
- **Link to hydrographic yearbook 2016 text** - https://www.bmlrt.gv.at/wasser/wasser-oesterreich/wasserkreislauf/hydrographische_daten/jahrbuecher/jahrbuch2016.html;
- **Link to hydrographic yearbook tables and evaluations** - https://wasser.umweltbundesamt.at/hydjb;
- **eHYD Portal** - www.ehyd.gv.at; and
- **Contact to subdepartment Water Balance at BMLRT** - wasserhaushalt@bmlrt.gv.at, Tel.: 0043 1 71100 606942.

Belgium

Capital city: Brussels
Inhabitants: 11 Million

Belgium is a federal state with three highly autonomous regions: Flanders in the north, Wallonia in the south, and the Brussels-Capital Region. Groundwater monitoring systems reflect this regional administration. The regional monitoring network of Wallonia is described below.

Flanders

INSTITUTIONAL SETTING

The application of Flemish and European legislation made it necessary to implement various target-specific monitoring networks.

The primary groundwater monitoring network in Flanders is managed by the Department of Operational Water Management of the Flanders Environmental Agency (VMM), and it is used for quantity, quality and operational monitoring.

For a better overview of the immense dataset, every monitoring well, (including the individual filters in the case of multilevel wells), is assigned to a specific measuring network. The classification is as follows (number of monitoring network and description):

1. Origin/manager unknown
2. Primary network – monthly measuring from VMM department Operational Water Management
3. Uncertain quality: mostly deeper measuring wells - initially part of the primary network, but with uncertain quality of monitored data and available well information from VMM department Operational Water Management
4. Measuring wells used for temporary projects from VMM department Operational Water Management
5. Wells from other Flemish and Belgian authorities or bodies
6. Wells from drinking water companies
7. Wells from private companies
8. Groundwater extraction wells
9. Phreatic monitoring network, especially shallow measuring wells, used for qualitative and operational monitoring from VMM department Operational Water Management
10. Usually phreatic shallow wells with a limited diameter from the WATINA (WATer IN NATURE) database operated by the Institute for Nature and Forest Research (INBO) and other nature conservation organizations. Biweekly for manual measurements and daily for measurements with a data logger
11. Wells that are constructed in the Flemish Regulations about Environmental Permits section 55 (VLAREM)

Some wells can belong to two different measurement networks, in particular networks 1 and 2. This occurs often at the level of screens.

PROCESSING

The VMM, the Department of Environment and the Department of Mobility and Public Works (MOW) work in a partnership to manage the Database Underground Flanders (DOV), which groups all information about the subsurface in the area of Flanders.

VMM produces two types of groundwater level indicators, namely for relative and for absolute status of groundwater. The analysis includes only phreatic aquifers and wells with continuous measurements for 11 years or more and an average head of 10 m-mv (meters below ground level) or less. The indicators are prepared monthly, and during very dry weather – also weekly. Performed analyses determine whether the groundwater level has increased or decreased compared to the last month and predict groundwater levels for the next month. Moreover, the locations of measurements are selected in a way to avoid the influence of human interventions as water extraction and drainage. The indicator shows the climate variability of the level.

Level measurements are supported by a SWAP model (Soil, Water, Atmosphere and Plant model). The model predicts the groundwater level for each measurement site based, among other things, on soil characteristics, the observed daily rainfall and evaporation. The results of the daily modelling are then combined with the monthly level measurements. The time series of daily simulated groundwater levels obtained in such way are processed into the indicator.

1. Indicator for the relative status of groundwater – What is the situation this time of the year?

For each monitoring location, the simulated groundwater level (combination of monthly level measurements and daily modelling with the SWAP) per day is compared with the simulated groundwater levels of the same day for the past 30 years. In statistical terminology: the percentile that corresponds to the groundwater level simulated for this year is read on the empirical cumulative distribution. The percentiles are divided into 5 classes: very low/very high (lower/higher occurs less than once in 10 cases), low/high (lower/higher occurs 1 to 3 times per 10 cases) and normal. The graph shows per day the percentage of monitoring stations that registered a very low, low, normal, high or very high groundwater level.

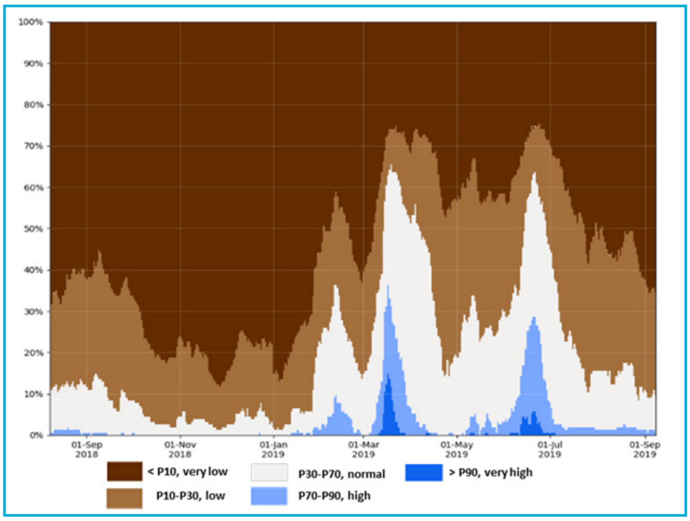


Fig. 83 – Relative status of the groundwater level for selected period (September 01 2018 to August 26 2018)

2. Indicator for the absolute status of groundwater – Is the groundwater historically low or high?

The simulated groundwater level (combination of monthly level measurements and daily modelling with the SWAP model) per day is compared to the simulated groundwater levels of all days in the past 30 years. The method shows the percentage of cases the groundwater level is lower (or higher) than the simulated groundwater level for the day in question. The percentiles are divided into 5 classes: very low / very high (lower / higher occurs less than 10% of the days), low / high (lower / higher occurs 10 to 30% of the days) and normal.

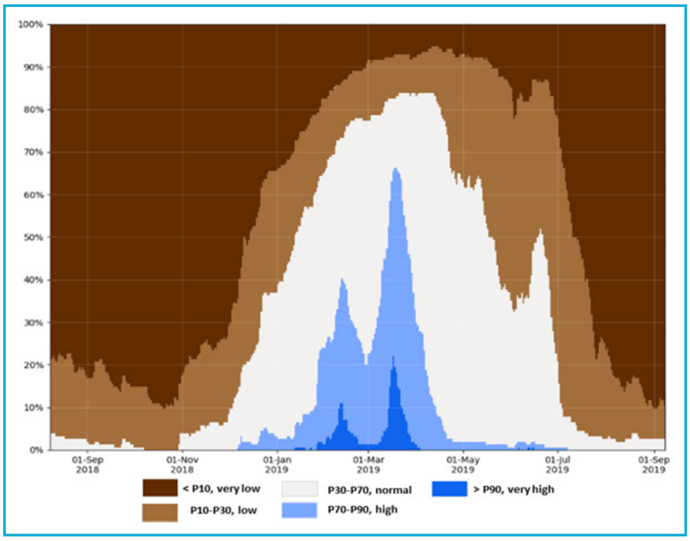


Fig. 84 – Absolute status of the groundwater level for selected period (September 1, 2018 to September 1, 2019)

3. Increase or decrease of the water table

This is determined by comparing the current groundwater level with the groundwater level of the previous month. If the change in the groundwater level at a measurement location is more than 5% of the difference between the 10th and 90th percentile of the groundwater level at that measurement site, this is regarded as an increase or decrease. Otherwise, the situation is considered stable.

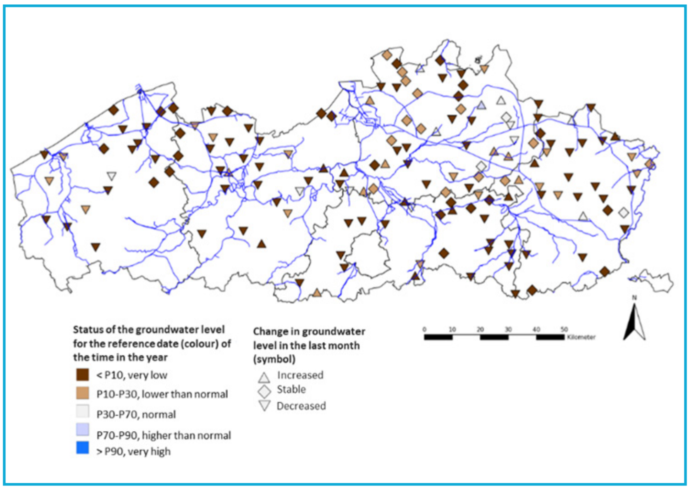


Fig. 85 – Example of groundwater level changes map

4. Prediction of groundwater levels

Three scenarios are modelled to predict future groundwater levels: a wet, a normal and a dry situation for the next month. The amount of precipitation in these scenarios correspond to a historical precipitation period from the Royal Meteorological Institute of Belgium (KMI) in Ukkel. For the wet and dry scenario, a month with a precipitation that occurs every 10 years is selected. For the normal scenario, a month with an average rainfall is chosen. The expected groundwater levels according to the three scenarios are compared in relative terms (all measurements on the same day of the year) and absolute (measurements on all days of the year) with the groundwater levels of the past 30 years. A warning is only given if the expected groundwater levels are very high / low historically or for the time of the year.

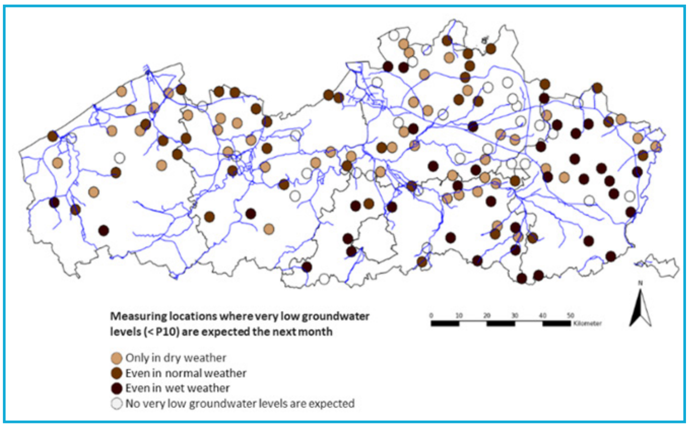


Fig. 86 – Example of groundwater levels projection for the next month

DISSEMINATION

All wells are currently available in the DOV database through its web-based portal (DOV-Explorer).

In total, it is possible to access the data of 62.443 wells, of which 17.109 screens correspond to level measurements and 12.590 to screens from which a groundwater sample was taken.

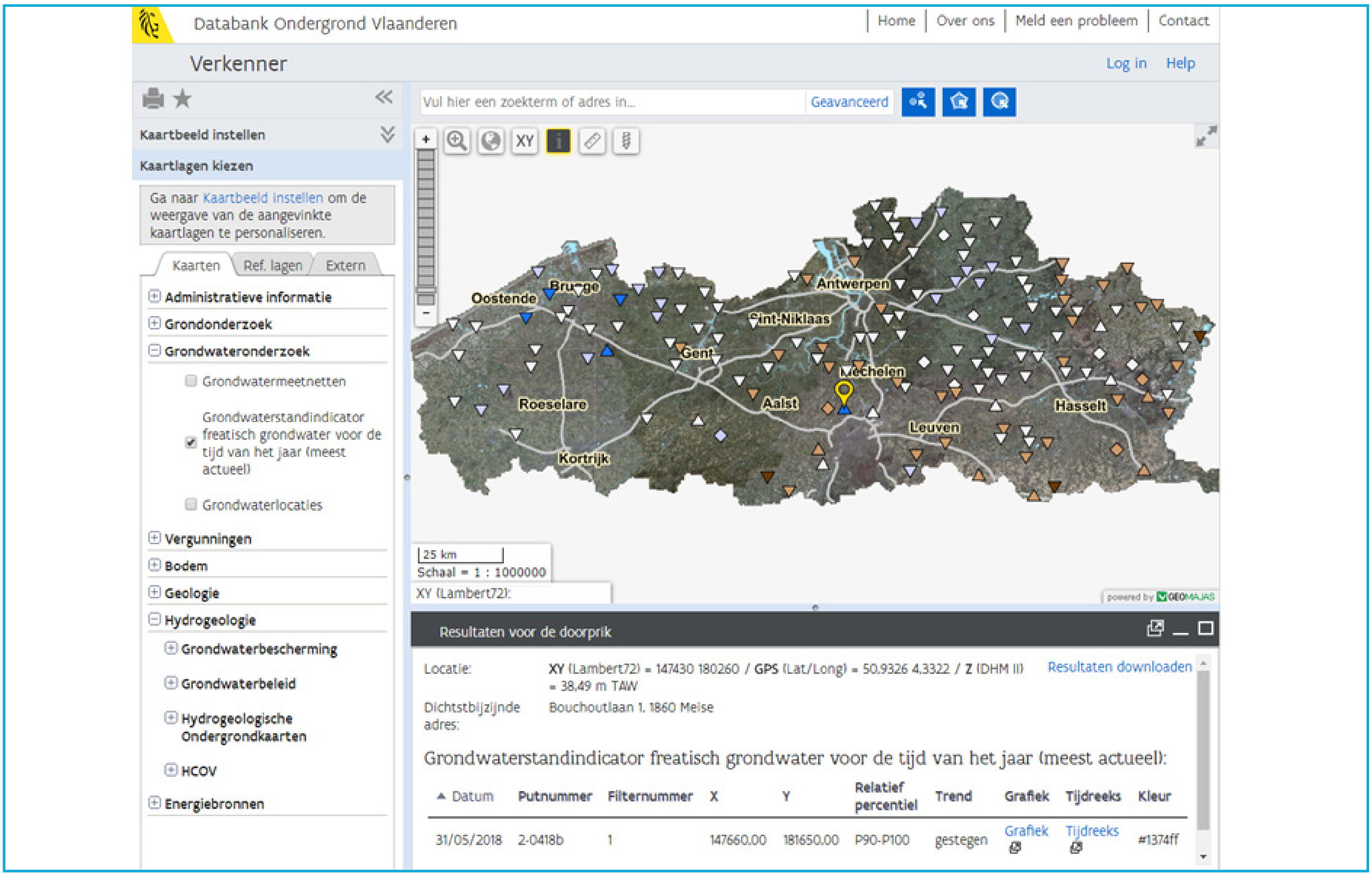


Fig. 87 – Groundwater monitoring network of Flanders, DOV-Explorer

Wallonia

INSTITUTIONAL SETTING

The Directorate of Groundwater (part of the Department of Environment and Water, General Directorate of Agriculture, Natural Resources and Environment) is responsible for both quality and quantity groundwater monitoring networks in Wallonia including the acquisition and the maintenance of the network.

CHARACTERISTICS OF THE NETWORK

The general quantitative monitoring network comprises more than 260 monitoring stations, where 235 are equipped with an automatic measurement system. Manual measurements are taken monthly to yearly depending on the availability of personnel, conditions of accessibility to the station, and others. Stations, where quantitative status is measured (178 in total), are part of a groundwater monitoring program that is setup according to the EU WFD and measuring changes in groundwater bodies as the basic units. The DCE monitoring network consists of 553 monitoring stations and both quantity and quality of groundwater is measured at 20 locations.

There is a separate emergency network set up for several karst aquifers equipped with automatic, real time measurements of water levels and discharge.

PROCESSING AND DISSEMINATION

Most of the data recorded via automatic data loggers is retrieved by remote transmission (GSM/GPRS). The data are then imported automatically into the AQUALIM database developed by the Directorate of Non-Navigable Watercourses (DCENN). The recorded hourly measurements are checked regularly via validation software that allows, if necessary, the correction of anomalies. Once validated, the data are consolidated into daily data and automatically transferred to the Dixsous database.

Groundwater level data are available via the portal PIEZ'EAU, where locations, meta data and time series are available for visualization and downloading.

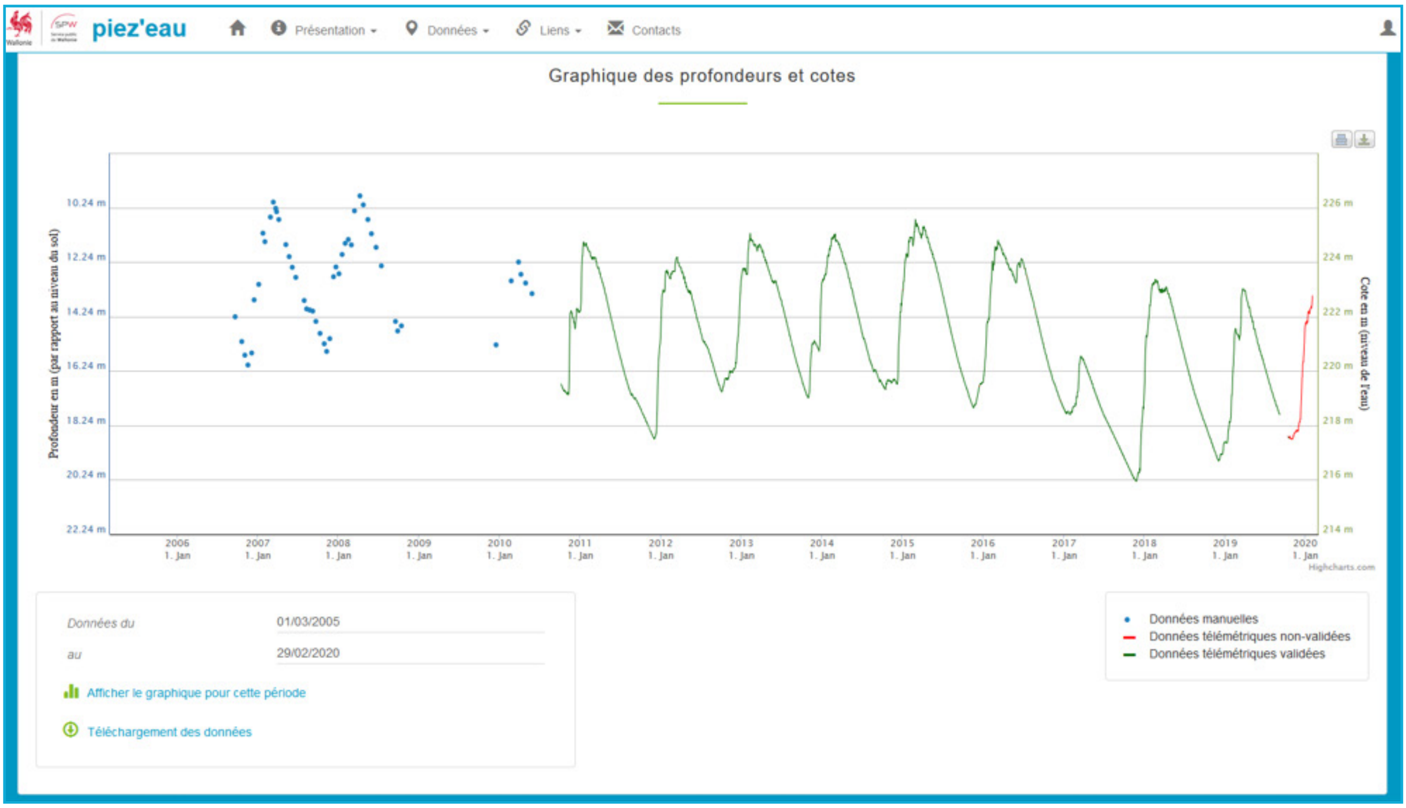


Fig. 88 – PIEZ'EAU portal

Time series can be exported as an image in various formats and the observations can be downloaded in PDF format.

In Dixsous database, the Geocentric Approach tool allows to visualise locations of piezometers and production wells on a map in a circle around given coordinate of the centre and given radius.

Sources

Flanders

- **Database Underground Flanders (DOV)** - https://www.dov.vlaanderen.be;
- **DOV, Classification of groundwater networks** - https://www.dov.vlaanderen.be/page/grondwatermeetnetten;
- **DOV-Explorer** - https://www.dov.vlaanderen.be/portaal/?module=verkenner&bm=9bba534d-0745-46ef-aa95-c31788c2266a**;**
- **DOV, Groundwater level indicators** - https://www.dov.vlaanderen.be/page/opbouw-grondwaterstandindicator;
- **Feedback from VMM** - received on 20-02-2020; and
- **SWAP model** - http://www.swap.alterra.nl.

Wallonia

- **Public Service of Wallonia. Status of Groundwater in Wallonia** - http://environnement.wallonie.be/frameset.cfm?page=http://environnement.wallonie.be/de/eso/atlas;
- **Dixsous database and Geocentric Approach tool** - http://carto1.wallonie.be/10SousInt/Default.asp;
- **Feedback from Wallonie Environment SPW** - received on 03-02-2020; and
- **PIEZ'EAU portal** - http://piezo.environnement.wallonie.be/GeneralPages.do?method=displayStationsMap&-time=2020-11-13%2016:29:49.621.

Croatia

Capital city: Zagreb
Inhabitants: 4 Million

INSTITUTIONAL SETTING AND PURPOSE

Croatian Waters is the national agency for water management, implementing the Croatian Water Act and the Regulations on Water Quality Standards. National monitoring is carried out for the assessment of groundwater quantity (groundwater levels in aquifers with intergranular porosity) and discharge of main springs (in karstic areas), as well as groundwater quality for the assessment of the status of groundwater bodies for the preparation of river basin management plans.

Croatian Meteorological and Hydrological Service (DHMZ) is a governmental body supporting the economic and sustainable development of Croatia by providing information on weather, climate, hydrological and ecological phenomena. DHMZ is in charge of hydrological and monitoring stations and the development and maintenance of various databases (meteorological, hydrological, air quality).

The objective of the national groundwater monitoring network of Croatia is to provide data to estimate the long-term state and trends of groundwater in the country, and provide input for the national water policy planning, regulatory agencies and the public.

CHARACTERISTICS OF THE NETWORK

The groundwater quantity monitoring network has 528 stations. Data are collected both manually and automatically (using data logger and automatic transmission). Automatic stations (data loggers) measure levels every day, and manual stations provide readings twice per week.

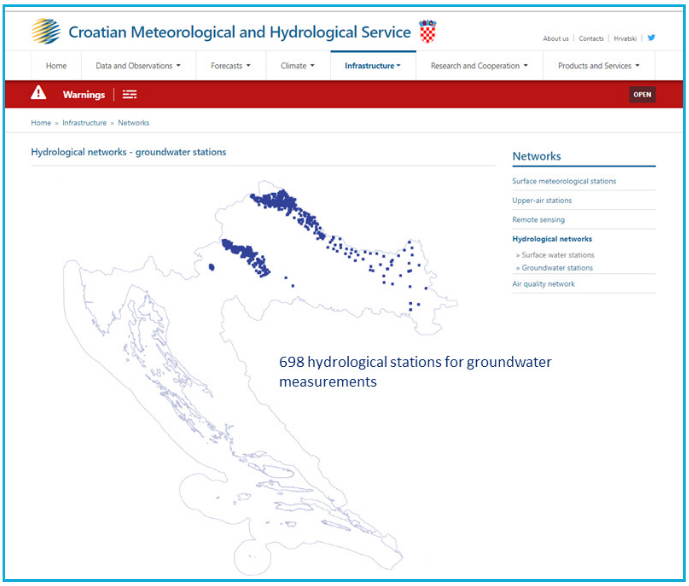


Fig. 89 – Location of groundwater monitoring stations in Croatia. Source: DHMZ

PROCESSING AND DISSEMINATION

Data are used to perform time series analysis, statistical analysis and modelling. The groundwater observations are available for governmental institutions, and upon request. Additionally, all data are reported to the Water Information System Europe (WISE).

Sources

- **Feedback from Croatia Waters (answer to form)** - received in 2018;
- **National Hydrometeorological Institute of Croatia, Hydrological networks, Groundwater stations** - https://meteo.hr/infrastruktura.php?section=mreze_postaja&param=hm&el=podzemne_hm;
- **National Hydrometeorological Institute. Hydrology Division** - https://hidro.dhz.hr; and
- **Water Information System for Europe** - https://water.europa.eu.

Czech Republic

Capital city: Prague
Inhabitants: 10 Million

INSTITUTIONAL SETTING AND PURPOSE

The groundwater monitoring network of the Czech Republic is managed by the Department of Groundwater of the Czech Hydrometeorological Institute. The Institute is based within the Ministry of the Environment and operates the only countrywide groundwater observation network. The Groundwater Department conducts observation and measurements of groundwater levels and spring discharge, processes obtained data and store those in a database. The department also analyses time series, calculates impact of regime on hydrogeological structures and estimates groundwater components for the hydrological balance.

CHARACTERISTICS OF THE NETWORK

The Czech Republic has a monitoring network consisting of 1,058 shallow wells, 414 deep wells and 320 springs. Wells are measured on daily basis by automatic stations as well as approximately half of the springs. The rest of the springs are monitored weekly by observers.

PROCESSING AND DISSEMINATION

Several maps with information about the status of the groundwater resource can be found on the website of the Czech Hydrometeorological Institute. Two types of evaluation and visualization for the data are used: one for shallow boreholes and springs, and one for deep boreholes.

Maps for shallow boreholes and springs

The evaluation is based on the comparison of current level of the water table (or yield response) with the corresponding values of the 1981-2010 period (30 years). Monthly level (yield) values correspond to the averages recorded usually four times that month (one value per week). Boreholes and springs that have datasets for at least 30 years are used for the analysis.

The period of 1981-2010 is also known as normal period. This period has been selected as a reference because most of the boreholes and springs have been observed since the 1970's and 1980's. Thus, it has sufficient long-term time-series.

The method is also applied only to assess weekly and monthly changes of the levels in shallow boreholes and springs. They are grouped on a basis of their location in river basins. The groups are defined as areas containing sub-basins (2nd and 3rd order river basins) and are determined by orographic watershed. The resulting classification and the colour of the area will be the average of the objects (boreholes or springs) within it, figure 90. The comparison makes use of the empirical Cumulative Frequency Curve (CFC).

The water level corresponding to the non-exceedance probability less than 5 % is labelled as extremely low, the band with 5-15 % as severely low and 15-25 % as moderately low. The level classified between 25-75 % is considered normal. The water level above normal is classified in a similar way. This method was employed to quantify the drought episode in 2015 in the Czech Republic. For example, to produce the map for September 2019, the monthly average was calculated using the Wednesday-values, and this result was compared with each value of September from 1981 to 2010 through the CFC curve.

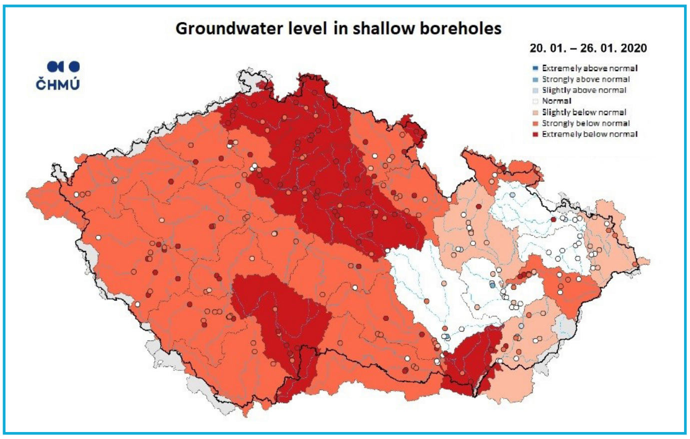


Fig. 90 – Results of weekly evaluation within river basins, for shallow boreholes. Source: Czech Hydrometeorological Institute

Maps for deep boreholes

The second type is monthly evaluation of deep boreholes and the principle of visualization is similar as for shallow boreholes and springs. The only difference is the application of hydrogeological zones (HGR) instead of the river basin groups. The HGR are based on the general hydrogeological map of the Czech Republic.

Deep boreholes lack of long time-series data, therefore the water level change is just compared with the previous month (figure 91).

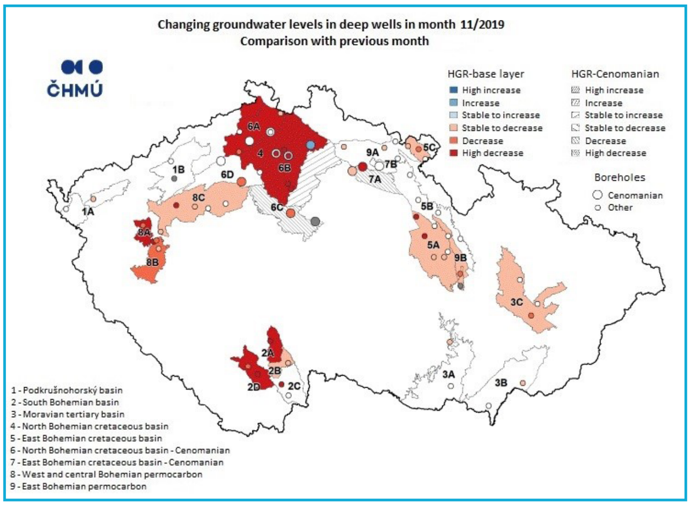


Fig. 91 – Groundwater level change in deep wells compared to the previous month. Source: Czech Hydrometeorological Institute

Flood Forecasting Service also provides data on groundwater levels and yields for shallow and deep wells, and springs. When an object is selected from the main map, an additional window opens with the information on yield change, figure 92. Data on water levels can be accessed through the View Region option.

The portal of the Czech Hydrometeorological Institute also publishes annual reports on hydrometeorological situation including the status of groundwater.

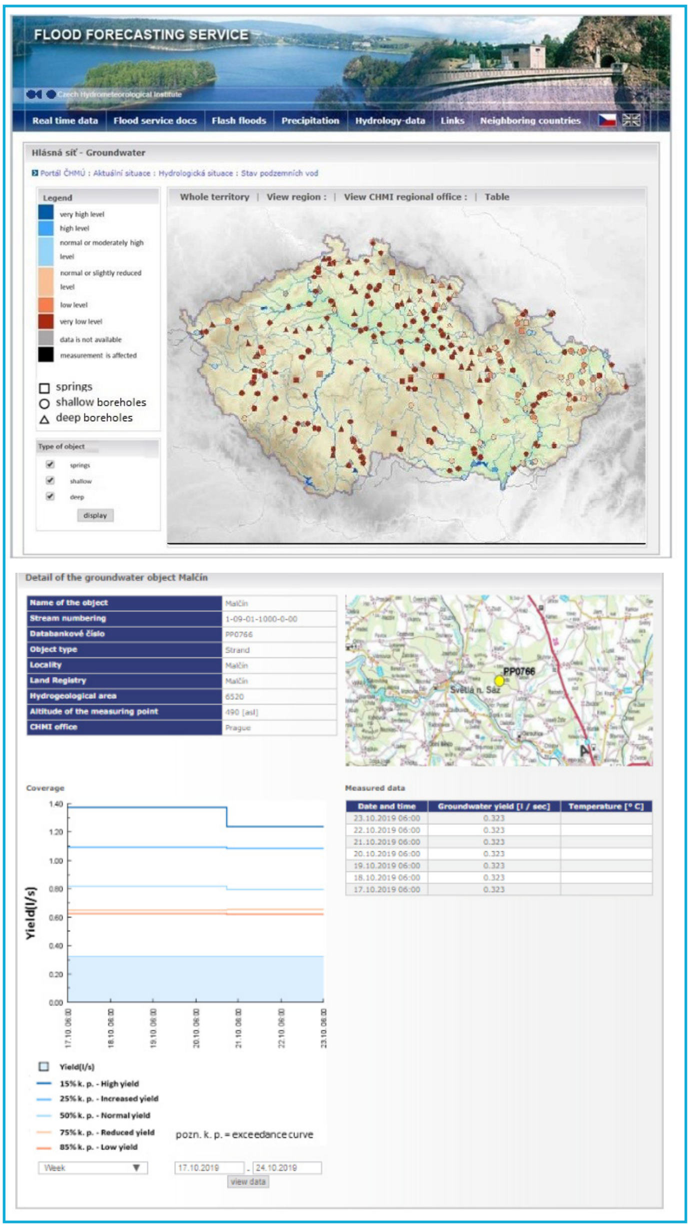


Fig. 92 – Flood Forecasting Service. Source: Czech Hydrometeorological Institute

Sources

- **Czech Hydrometeorological Institute (In English)** - http://portal.chmi.cz/?l=en;
- **Czech Hydrometeorological Institute, Flood Forecasting Service** - http://hydro.chmi.cz/hpps/hpps_pzv.php;
- **Czech Hydrometeorological Institute, Groundwater portal** - http://portal.chmi.cz/aktualni-situace/hydrologicka-situace/stav-podzemnich-vod;
- **Czech Hydrometeorological Institute, Hydrological information and reports** - http://portal.chmi.cz/aktualni-situace/hydrologicka-situace/hydrologicka-situace; and
- **Feedback from the Czech Hydrometeorological Institute** - received on 04-02-2020.

Denmark

Capital city: Copenhagen
Inhabitants: 5 Million

INSTITUTIONAL SETTING AND PURPOSE

The Ministry of Environment and Food of Denmark is in charge of environmental protection, farming and food production, with the Danish Environmental Protection Agency as one of the Departments in the Ministry.

The National Groundwater Monitoring Network (GRUMO) is part of the National Monitoring Program for Aquatic Environment and Nature (NOVANA). GRUMO, along with other related monitoring programmes as the Agricultural Catchment Monitoring Program (LOOP) included in NOVANA, was initiated in 1988 to monitor quality and quantity of groundwater throughout the country.

The National Geological Survey for Denmark and Greenland (GEUS) acts as a data centre and scientific advisor/reporter for the collection of groundwater and borehole information.

The objective of the groundwater monitoring programme, GRUMO, is to establish representative time series for the quality and quantity of the groundwater resources to ensure good quality of drinking water for the future. In addition to this, the program aims to provide data to monitor status and trends of groundwater bodies (administrative units to be used according to the WFD). Data collected are also to be used in the development of models for river basin management.

The Agricultural Catchment Monitoring Program (LOOP), which has a groundwater component, is dedicated to monitoring groundwater quality in the unsaturated zone, tile drains and shallow groundwater (approx. 3 to 5 meters depth) in six agricultural catchments in sandy and clayey areas across Denmark, mainly focusing on leaching of nutrients (N and P) to groundwater.

Moreover, the National Groundwater Level Monitoring Programme (Det Nationale Pejleprogram) was set up to monitor groundwater levels through sounding stations within five regional areas.

GRUMO was originally designed to provide a picture of the groundwater's condition and development in a number of selected catchments – the GRUMO areas – which were considered to be representative for groundwater of the country. The GRUMO program has since been updated and adapted continuously on the basis of greater knowledge and due to the varying administrative needs, including the fulfilment of the reporting obligations under EU directives, particularly the WFD and the Nitrates Directive.

CHARACTERISTICS OF THE NETWORK

Groundwater levels are monitored through approx. 1,000 GRUMO monitoring wells and the National Groundwater Level Monitoring Programme, where the groundwater level readings are taken several times daily for approximately 160 boreholes. In addition, all water abstractions (except single households) are reported on an annual basis as abstracted water volumes to the joint public database Jupiter hosted by GEUS.

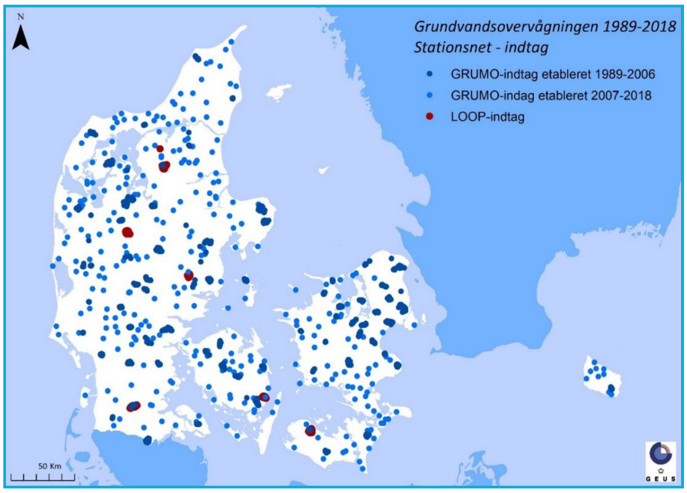


Fig. 93 - Monitoring points in the 73 groundwater monitoring areas ('GRUMO-indtag' 1989-2006) and monitoring wells in the distributed network established in the period 2007-2017 for the WFD ('GRUMO-indtag' 2007-2018). LOOP monitoring of six agricultural catchments are also included, one of which was later closed in Central Jutland. (Source: Thorling et al., 2019)

Monitoring wells included in the program in 2017, with a top screen depth of approximately 40 meters, are more or less evenly distributed over Denmark, while deeper monitoring points show significant regional differences. Thus, on Bornholm (easternmost island), the vast majority of monitoring points are within the upper 20 meters, while the vast majority of deep boreholes (80-372 m below the ground surface, b.g.s.) are found in Jutland (continental Denmark) with the largest occurrence in southern Jutland.

The situation is different for monitoring wells and "waterwork wells" (wells for drinking water) in 2018. 50-60% of GRUMO monitoring points are established within the upper 20 m, while just 10% are established deeper than 50 m below the ground surface. In the waterworks wells, the screens are placed deeper. Here, 50% of the waterworks boreholes have the top of the screen located at a depth greater than 40 m b.g.s., and 10% at depths greater than 80 m b.g.s.

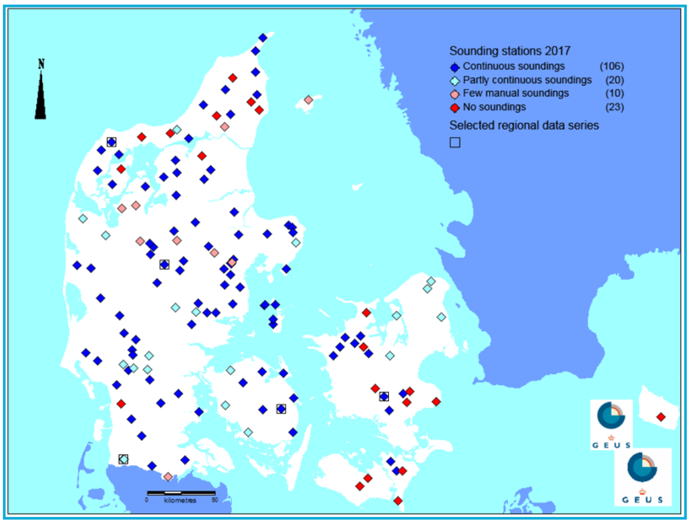


Fig. 94 - Geographical distribution of wells that are part of the National Groundwater Table Monitoring Programme in 2017, including five regional indicator measurement stations with long time series (Source: GEUS)

PROCESSING AND DISSEMINATION

All monitoring data are freely available on GEUS homepage. figure 95 shows the location of boreholes through the GEUS portal. It is also possible to download data in Excel format.

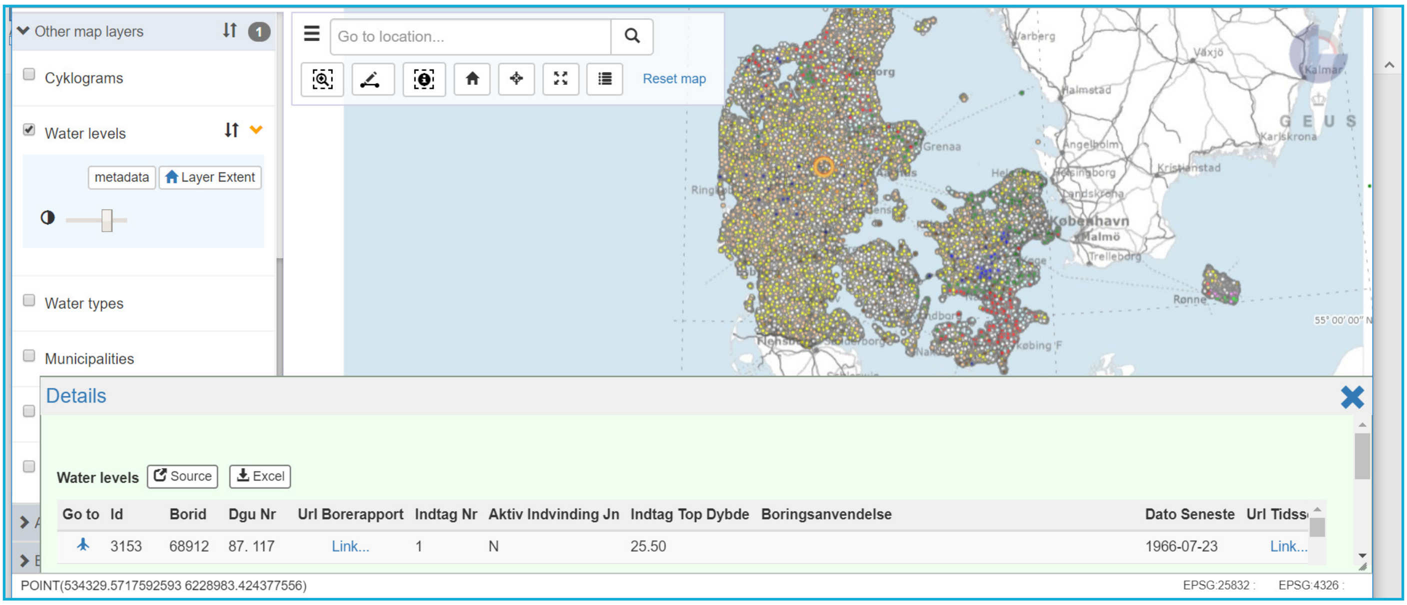


Fig. 95 – GEUS portal for groundwater analyses with points measuring water level. Source: GEUS)

Sources

- **Data management by GEUS** - https://www.eea.europa.eu/publications/92-9167-032-4/page005.html;
- **Feedback from GEUS** - received on 27-01-2020;
- **Geological Survey of Denmark and Greenland (GEUS)** - https://www.geus.dk/vandressourcer/overvaagningsprogrammer/grundvandsovervaagning/;
- **Hansen B., Thorling L., Dalgaard T., Erlandsen M. 2010. Trend Reversal of Nitrate in Danish Groundwater - a Reflection of Agricultural Practices and Nitrogen Surpluses since 1950** - https://pubs.acs.org/doi/pdf/10.1021/es102334u; and
- **Jupiter (GEUS's nationwide drilling database for groundwater, drinking water, raw material, environmental and geotechnical data)** - https://data.geus.dk/geusmap/.

Estonia

Capital city: Tallinn
Inhabitants: 1 Million

INSTITUTIONAL SETTING AND PURPOSE

The Ministry of Environment of the Republic of Estonia is the general coordinator of the monitoring programme in cooperation with the Environmental Board, the Environmental Inspectorate, the Environment Agency and the Environmental Investment Centre.

The National Environmental Monitoring Programme consists of sub-programmes, and one of them is the Groundwater Monitoring programme. This sub-program is divided into sections: monitoring of groundwater bodies (31 units) and monitoring of groundwater in the nitrate vulnerable zone. All groundwater bodies are subject to surveillance monitoring.

Changes in groundwater levels are monitored for the evaluation of the quantitative status of groundwater. The network for monitoring the chemical status of groundwater aims at providing a reliable evaluation of groundwater quality at every groundwater body. The monitoring network also aims to describe the natural and anthropogenic changes in the chemical composition of groundwater and the significant and constant changes in pollutant concentrations; and to evaluate the achievement of environmental objectives for areas that are dependent of groundwater and need protection. Based on the data collected, it is possible to plan the sustainable consumption of groundwater, prevent depletion and to assess the quality and suitability of groundwater for drinking purposes.

CHARACTERISTICS OF THE NETWORK

The monitoring of the quantitative status of groundwater bodies includes measuring groundwater levels and, if necessary, groundwater flow in springs and discharge points in water courses or other inland bodies of surface water. In relatively homogeneous confined groundwater bodies (sand, sandstone), it is sufficient to measure the water level 3-5 times per month and in homogeneous unconfined groundwater bodies, 5-10 times per month. The measuring frequency of Silurian-Ordovician confined groundwater bodies with fissures and karst should be 5-10 times per month and in unconfined groundwater bodies with fissures and karst 10 times per month.

Data about pollutants which put the good status of a groundwater body at risk or cause a bad chemical status of a groundwater body are collected during operational monitoring of chemical status.

In areas at risk of agricultural pollution, nitrogen compounds (especially NO3 and NH4) must be monitored, and, depending on the level of protection of the groundwater body, also the possible content of pesticide and fertilizer residues in shallow layers. Additionally, the content of nitrites and phosphorus-containing compounds in groundwater should be also monitored.

The monitoring program also includes the conductance of surveys. They are used to identify pollution sites, assess the groundwater status of contaminated and polluting areas and plan implementation of safeguard measures.

The monitoring programme has been prepared in accordance with the WFD for a period of 6 years, therefore it may be subjected to changes upon concluding monitoring agreements.

PROCESSING AND DISSEMINATION

Monitoring networks of groundwater bodies and nitrate vulnerable zones are presented with the Esri Map story on the Environmental Agency website, figure 96. When a user selects an observation point, the information on its relation to a river basin, groundwater body name and ID, hydrogeological layer, xy coordinates, number of water level measurements per year, sensor type are shown.

The National Support Observation Network of Estonia consists of stations recording groundwater levels and the main physical and chemical parameters.

Updated monitoring programmes are available on the website of the Ministry of Environment. Results of monthly and annual average, minimum and maximum groundwater levels of monitoring wells, results of chemical analysis and field measurements are transferred into a groundwater monitoring database.

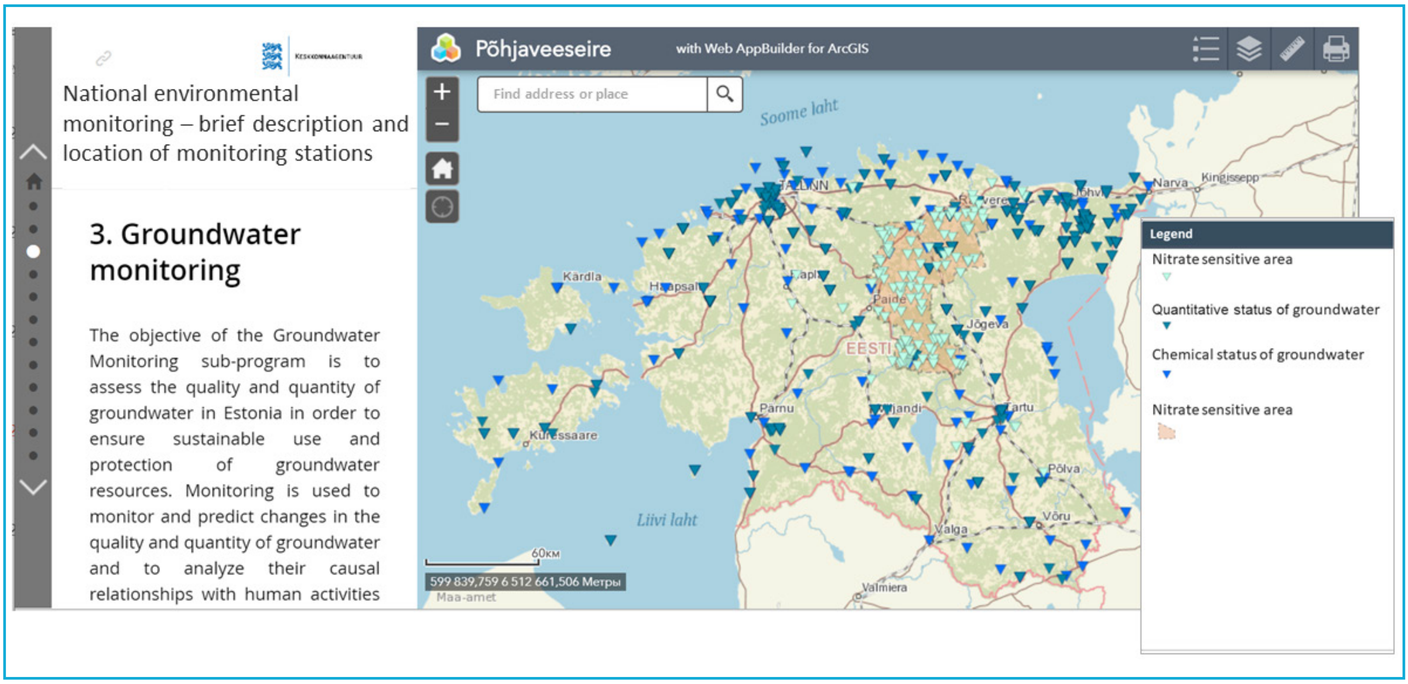


Fig. 96 - ESRI map story compiled with the National Environmental Monitoring Program

Fig. 97 - Antu blue springs lake, Estonia, Europe, by: Artenex

Sources

- **Environment Ministry of Estonia, groundwater** - https://www.envir.ee/et/eesmargid-tegevused/vesi/pohjavesi;
- **Feedback from the Ministry of the Environment** - received on 22-04-2020;
- **The Environmental Agency of Estonia, environmental monitoring** - https://www.keskkonnaagentuur.ee/et/seire;
- **Environment Ministry of Estonia, groundwater monitoring system in Ida-Viru County** - https://www.envir.ee/et/eesmargid-tegevused/vesi/pohjavesi/pohjaveeseire-susteem-ida-viru-maakonnas; and
- **Updated monitoring programmes, Ministry of Environment** - http://www.envir.ee/et/kavade-ja-programmide-eelnoud.

Finland

Capital city: Helsinki
Inhabitants: 5 Million

INSTITUTIONAL SETTING AND PURPOSE

The Ministry of Environment and the Ministry of Agriculture and Forestry are in charge of nation-wide surface and groundwater monitoring programmes in Finland. These programmes are coordinated by the Finnish Environment Institute (SYKE).

The actual water quantity monitoring is carried out by private laymen or by automatic monitoring equipment. Groundwater quality sampling is coordinated by SYKE and the regional ELY-centres (Centres for Economic Development, Transport and the Environment)..

CHARACTERISTICS OF THE NETWORK

The national groundwater monitoring network of Finland has ca. 95 monitoring stations distributed in 13 administrative regions, figure 98. The monitoring stations represent variable climatic conditions, soil types and terrains where human impact has been subtle. A typical groundwater station has about ten observation tubes and one observation well. Groundwater levels are measured manually twice a month, and the average record length is almost 40 years. Additionally, many stations have groundwater table data loggers with automatic transmission of hourly data. Groundwater quality is monitored 2-4 times per year, which is dependent on the monitoring programme of each station.

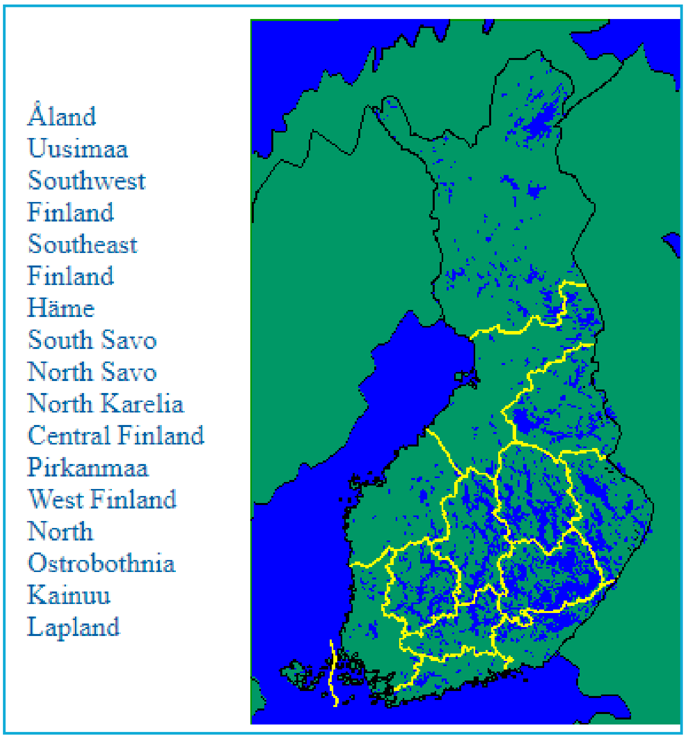


Fig. 98 - Administrative regions with groundwater level monitoring. Source: SYKE

PROCESSING AND DISSEMINATION

Outcomes of groundwater quantity and quality monitoring performed within the national programme are stored into the groundwater data system (POVET). The time series of groundwater levels are also presented in graph form e.g. on SYKE's website. By clicking on an administrative region, groundwater level graphs for the previous year are shown, figure 99. The averaged groundwater levels of the monitoring stations are presented in metres above sea level, as recorded every two weeks at monitoring sites around Finland, together with long-term monthly averages, maximums and minimums. For fully automated stations, daily groundwater levels are shown.

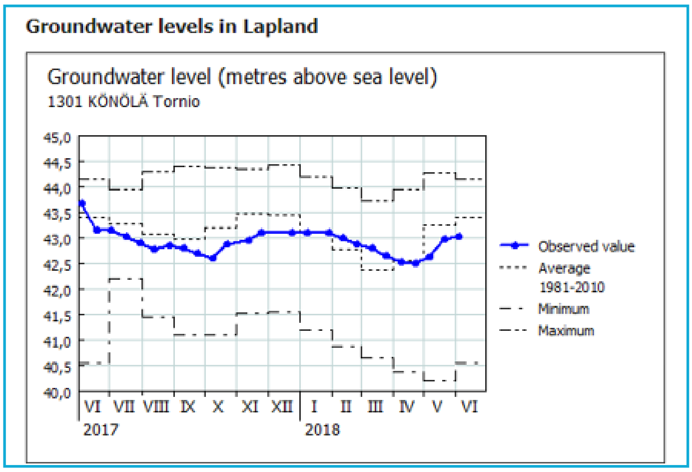


Fig. 99 - Administrative regions with groundwater level monitoring. Source: SYKE

Short-term groundwater table forecasts are simulated with the Watershed Simulation and Forecasting System (WSFS), developed by SYKE, using the data from the groundwater stations, figure 100. The water simulation uses groundwater quantity data e.g. for forecasting floods. Short-term forecasts are calculated for approximately 50 stations.

A suggestive model of nation-wide hypothetical groundwater tables is calculated with the WSFS based on approximately 50 groundwater stations, figure 101. The map classifies groundwater levels as: above the highest value, above the annual average, above average, below average, below the annual average and below the lowest value. The system also forecasts groundwater levels for the next 3 and 9 days. Detailed maps in the same section allow users to see contour lines of groundwater levels across Finland for the last 90 days in mm.

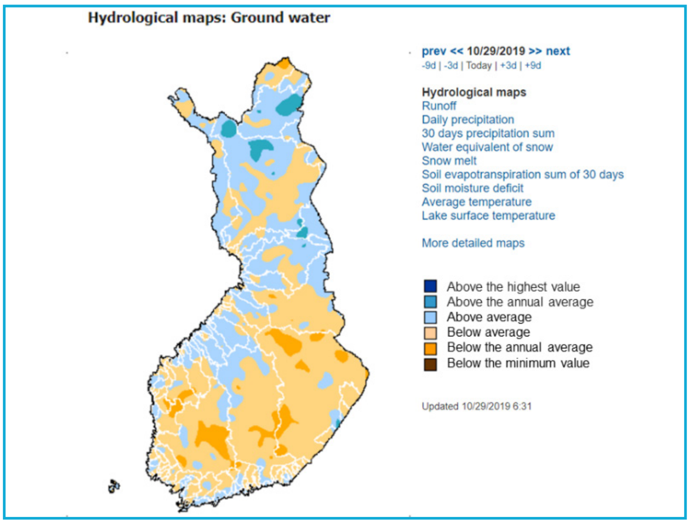


Fig. 100 - Suggestive simulation of groundwater level in Finland as of October 29, 2019. Source: SYKE

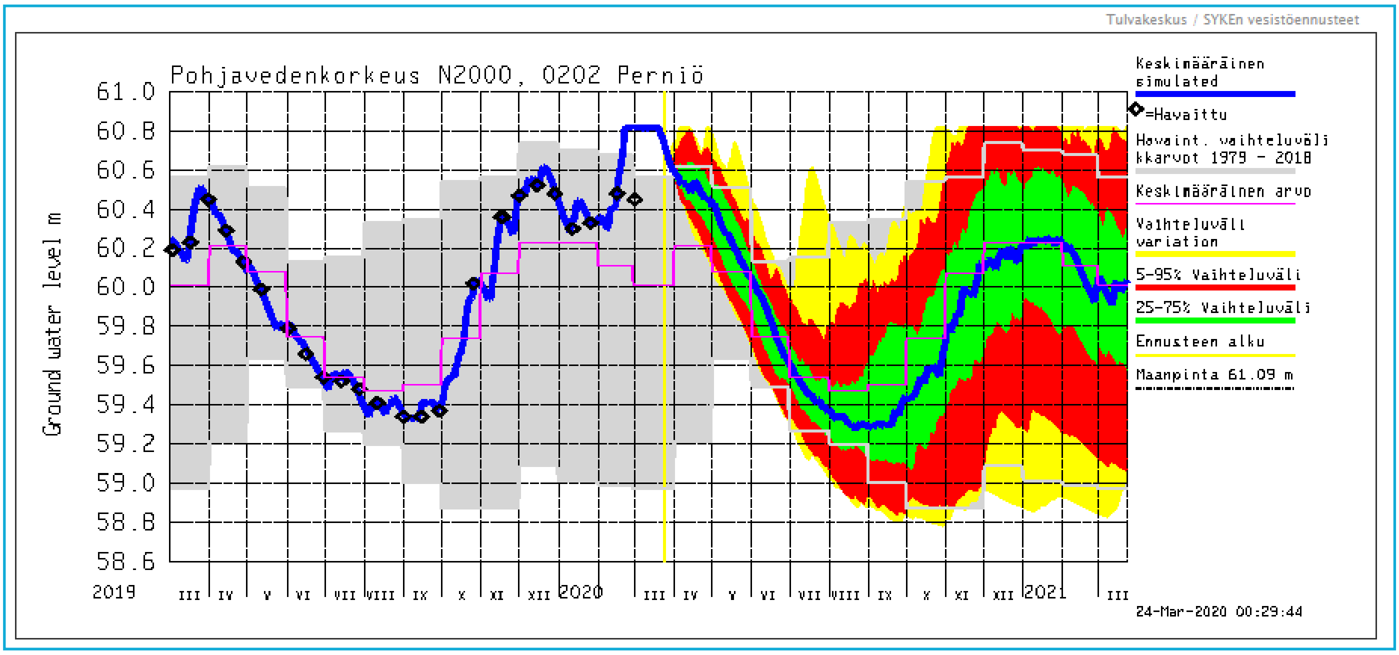


Fig. 101 - Short-term forecast and actual observations for Perniö groundwater station

Sources

- **Environment.fi – Joint website of Finland's environmental administration. Quantitative and chemical status of groundwater** - https://www.ymparisto.fi/fi-FI/Vesi/Pohjavesien_tila;
- **Environment.fi. Monitoring of groundwater status** - https://www.ymparisto.fi/fi-FI/Vesi/Pohjavesien_tila/Pohjavesien_tilan_seuranta;
- **Environment.fi. Groundwater levels in Finland** - http://wwwi3.ymparisto.fi/i3/paasivu/eng/pohjavesi/pohjavesi.htm;
- **Environment.fi. Hydrological maps, groundwater** - http://wwwi2.ymparisto.fi/i2/90/gvyy2/tanaan_en.html;
- **Environment.fi. Water model system, groundwater forecast** - http://wwwi2.ymparisto.fi/i2/pohjavesiasemat.html;
- **Environment.fi. Water maps: Groundwater replenishment within 90 days** - http://wwwi2.ymparisto.fi/i2/94/finngvdfb.html;
- **Environment.fi. Hydrological forecast and maps** - https://www.environment.fi/en-US/Waters/Hydrological_situation_and_forecasts/Hydrological_forecasts_and_maps;
- **Feedback from the Finnish Environment Institute (SYKE) -** received on 15-04-2020;
- **Finnish Environment Institute SYKE** - Watershed simulation and forecasting system (WSFS) Brochure (2 and 6 pages); and
- **Lavapuro, M., Lipponen, A., Artimo, A., & Katko, T.S. (2008). Groundwater sustainability indicators: testing with Finnish data. Available in** - https://helda.helsinki.fi/bitstream/handle/10138/234763/ber13-5-381.pdf?sequence=1.

France

Capital city: France
Inhabitants: 65 Million

INSTITUTIONAL SETTING AND PURPOSE

The Ministry of the Ecological and Inclusive Transition (MTES) is in charge of water management and implements the EU Water Framework Directive in France. Surveillance for groundwater quality is mentioned as one of the water policy actions on the ministerial website. There are various groundwater monitoring networks in France, and it is not always clear which governmental institution manages them.

CHARACTERISTICS OF THE NETWORK

At a national level, the National Quantitative Monitoring Network for Groundwater (RNESP) monitors the quantity of aquifers of national interest. Minimum monitoring point density has been specified for this network, according to the CIS/EU guidelines type and size of the aquifer: 1 point every 500 km2 in unconfined aquifers (including wetlands), 1 point every 1000 km2 for small confined aquifers of less than 1000 km2, 1 point every 3000 km2 for large confined aquifers of more than 1000 km2, and 1 point every 7000 km2 in deep aquifers (higher densities have sometimes being selected). The network has 1,843 stations, among them 1,775 are active at the moment. According to the CIS/EU guidelines, the minimum frequency of monitoring is weekly, and monthly for confined aquifers.

Other groundwater monitoring networks are the parts of the surveillance network reporting results to Eaufrance in 12 regions. These networks provide an overview of the status of water in each catchment and sub-catchment, including groundwater.

PROCESSING AND DISSEMINATION

The National Portal for Access to Groundwater Data (ADES), maintained by the French Geological Survey (BRGM) and the product of the Water Information System (SIE), is the national database of public quantitative and qualitative groundwater data for metropolitan France and overseas departments. Main partners in data provision are BRGM, French Office for the Biodiversity, Water Agencies; Regional Directions for the Environment, Planning and Housing (DREAL); Regional Health Agencies (ARS), local authorities and other public bodies. Regularly updated information is available by point, river basin, region and aquifer. Currently, 15,992,803 water levels and 82,956,553 water analyzes are available online.

Groundwater level monitoring stations can be accessed online, and their metadata and data can be visualized and exported (including coordinates), figure 102.

For 1,450 monitoring points of the 1,600 managed by the BRGM, observation data are available in real time. They can be viewed on ADES every day.

Fig. 102 - Well BSS001MXUY from Loire-Bretagne Basin. Source: ADES Portal

Since 1988, the BRGM is preparing the National Hydrological Situation Bulletin (BSH) for groundwater. BSH describes the quantitative status of aquatic environment (streamflows, groundwater, reservoirs) through indicators.

The Standardised Piezometric Indicator (IPS), in use since 2017, is set up to provide a homogeneous info about the status of aquifers. It is based on other indicators such as the Standard Precipitation Index (SPI) and the Standardised Groundwater level Index (SGI).

To calculate the IPS the following steps are applied:

- The construction of piezometric levels series over the period of N years.
- Calculation of the average piezometric level over n months (the current month and the n-1 previous months) with n=3, 6, 9, 12 months or more. These months represent different time scales that may correspond to periods of precipitation deficit.
- A continuous curve of IPS n-month is obtained over the entire period of N years.

The IPS_1 month allows to compare the average level of the current month with the values of the same month of the N years. IPS_6 month compare the average level over the last 6 months (including the current month), etc.

"Current month" means the month preceding the edition of the bulletin, for example for the bulletin on June 1st, the current month corresponds to the data of May. The rolling average of groundwater levels and the IPS value is calculated every month (12 values of IPS per year). Example: figure 103 shows the density histogram of the average levels of the months of May and the fit of a probability density estimator.

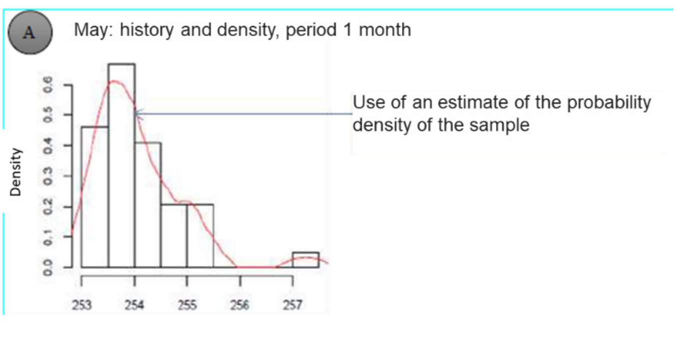


Fig. 103 - The density histogram of the average levels of May months. Source: Gourcy et al, 2018

Figure 104 (B) shows the cumulative distribution of adjusted frequency of the average levels of the month of May, projected over cumulative frequency in figure 104 (C).

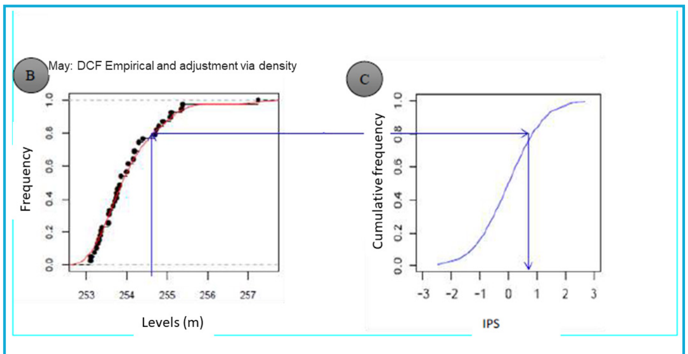


Fig. 104 - The cumulative distribution of adjusted frequency of the average levels of the month of May (B) and cumulative frequency (C). Source: Gourcy et al, 2018

The value of IPS ranges from -3 to +3, table 4. Seven classes are defined based on the IPS values, from "very low" to "very high".

IPS Classes			
Min.	Max.	Level qualification	Return period
≥1.282	≤3.000	Very high level	> 10 years wet
≥0.842	<1.282	High level	From 5 to 10 years wet
≥0.253	<0.842	Moderately high levels	From 2.5 to 5 years wet
≥-0.253	<0.253	Levels close to the average	From 2.5 years wet to 2.5 years dry
≥-0.842	<-0.253	Moderately low levels	From 2.5 to 5 years dry
≥-1.282	<-0.842	Low levels	From 5 to 10 years dry
≥-3.000	<-1.282	Very low levels	> 10 years dry

Table 4 - IPS classification. Source: Gourcy et al, 2018

The IPS is calculated for all indicators points when data of 15 years or more are available. For stations with a short series of historical data (10 to 15 years), a Position Indicator (IP) is calculated monthly:

Where:

$$IP = \frac{(moy_{mois} - mini_{serie})}{(max_{serie} - min_{serie})} \cdot 100$$

- **moymois:** groundwater level monthly average of the current month
- **miniserie:** monthly minimum groundwater level of the series
- **maxiserie:** monthly maximum of groundwater levels of the series
- **maxserie** and **minserie** include the current month. Therefore, the indicator position is between 0% (low water never encountered before) and 100% (high water situation never encountered before).

The classes of position indicators will be distributed similarly to the IPS from -3 to +3, between 0 and 100%, table 5.

IP Class	Classification
≥ 90%	very high levels
≥75% and <90%	high levels
≥55% and <75%	moderately high levels
≥45% and <55%	around the average
≥25% and <45%	moderately low levels
≥10% and <25%	low levels
<10%	very low levels

Table 5 - IPS classification

BRGM produces press publications of the groundwater level status in France every month including a groundwater trend map, figure 105. The publications describe the evolution of groundwater levels and expected trends.

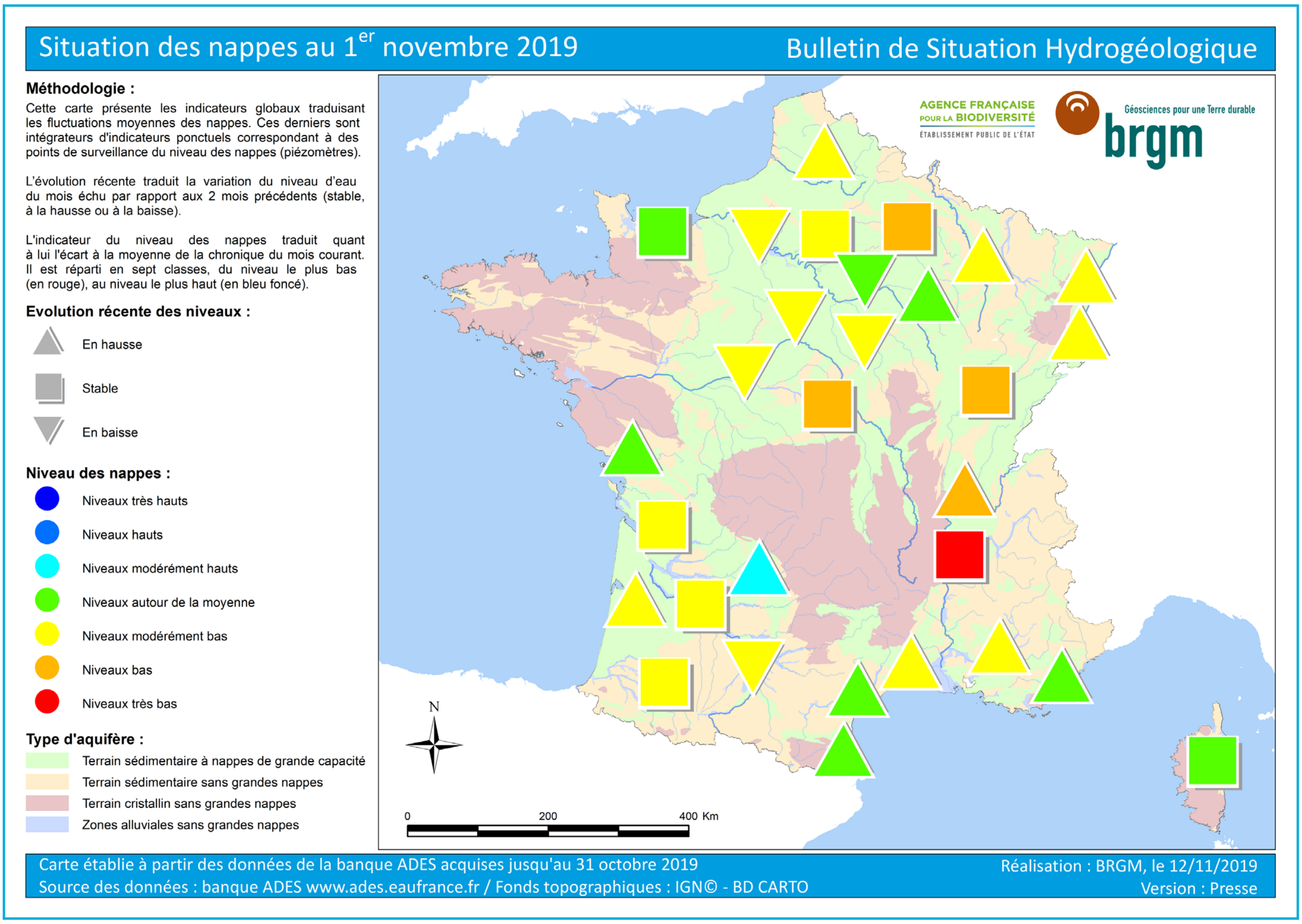


Fig. 105 - State of groundwater in France in November 2019. Source: BRGM

The map shows indicators that reflect the average fluctuations of the water levels with respect to the previous 2 months (Recent evolution: stable – square, levels go up – triangle or levels go down - inverted triangle).

The colours show how much the current values move far away from the historical average. The range is divided into seven classes, from the lowest level (in red) to the highest (in dark blue).

Sources

- **ADES. National heritage network for quantitative monitoring of groundwater** - http://www.ades.eaufrance.fr/Fiche/Reseau?Code=0000000029;
- **ADES, National portal for access to groundwater data** - https://ades.eaufrance.fr;
- **Feedback from BRGM** - received on 25-03-2020;
- **Gourcy L., Seguin J-J., Hélène B., Mougin B., Vigier Y., Nicolas J., Loigerot S., Allier D, 2018. Herramientas para la Gestión de las Aguas Subterráneas durante Eventos Extremos. El Agua Subterránea: Recursos sin Fronteras: Acuíferos Transfronterizos, El Agua Subterránea y las Ciudades. Planificación y Gestión. Rodolfo Fernando García [et al.]. Primera Edición. 2018. p 165-170** - ISBN 978-987-633-535-5;
- **Groundwater levels on 1st November 2019** - https://www.brgm.fr/actualite/nappes-eau-souterraine-1er-novembre-2019;
- **Ministry of the Ecological and Inclusive Transition. Water management in France** - https://www.ecologique-solidaire.gouv.fr/gestion-leau-en-france; and
- **Monitoring programs** - http://surveillance.eaufrance.fr.

Germany

Capital city: Berlin
Inhabitants: 83 Million

INSTITUTIONAL SETTING AND PURPOSE

The Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB) is responsible for regulating the water resources through the Federal legislation. State Geological Surveys (SGDs) are the specialized institutions of federal states in charge of subsoil information, including groundwater. The federal states are responsible for collection, processing and dissemination of regional data and related products. The case of the federal state of Bavaria is shown below as an example.

The Bavarian Environment Agency (LfU) offers several web services. Among these, the Low Water Information Service (NID) of Bavaria was created in order to classify the actual situation and to offer decision makers and the public a basis to evaluate and, if necessary, to prepare against dry periods on an early stage. The NID provides data from regional monitoring networks (surface water and groundwater) and, in case of low water conditions, publishing short reports interpreting those data.

CHARACTERISTICS OF THE NETWORK

The Bavarian Environment Agency operates, together with the regional water authorities, a monitoring network of around 3,000 groundwater monitoring sites. This network consists of the basic network (620 monitoring sites), the compaction network (341 monitoring sites) and regional networks (2,063 monitoring sites). Additionally, a network of around 110 spring sites is monitored.

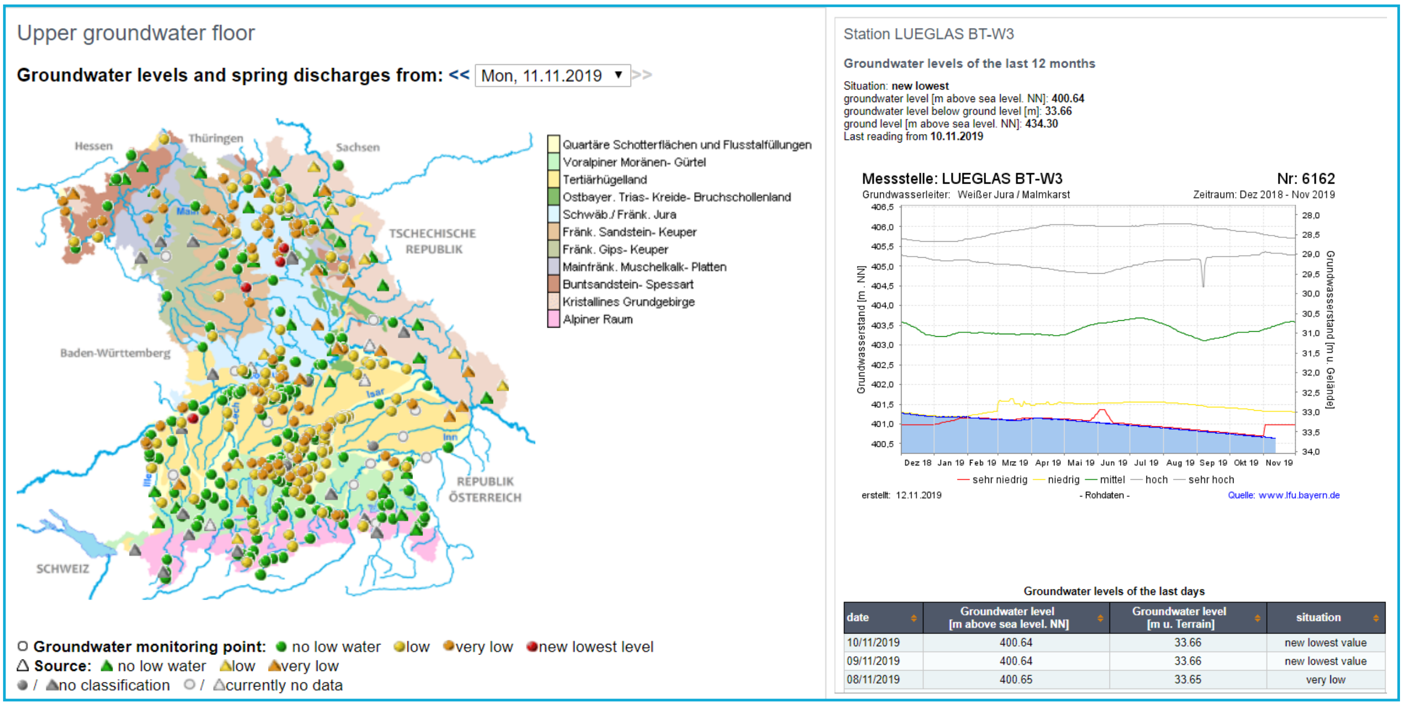
A high number of monitoring sites is equipped with continuously recording instruments (electronic data loggers) to collect the groundwater data. The basic network focuses on supra-regional and representative aquifers with high water management importance. The monitoring sites in the basic network are usually equipped with remote data transmission devices. The compaction network complements the work of the basic network. It is usually used for hydrogeological tasks for a limited period or only at certain times. The regional networks are set up for small-scale groundwater investigations, mainly for a limited period. The depth of the monitoring sites ranges between 2 m to 1400 m below surface.

PROCESSING AND DISSEMINATION

The NID web service offers groundwater data of selected monitoring sites to the public and various users such as planners or municipalities. Overview maps with a daily groundwater classification of each monitoring site situated in shallow (figure 106, left) and deeper aquifers (figure 107, left) are provided. This information is also available in a table format. When a user selects an observation well from the map or the table, time-series of groundwater levels are presented for the entire monitoring period, an annual period (figure 106 and figure 107, right) as well as an annual comparison.

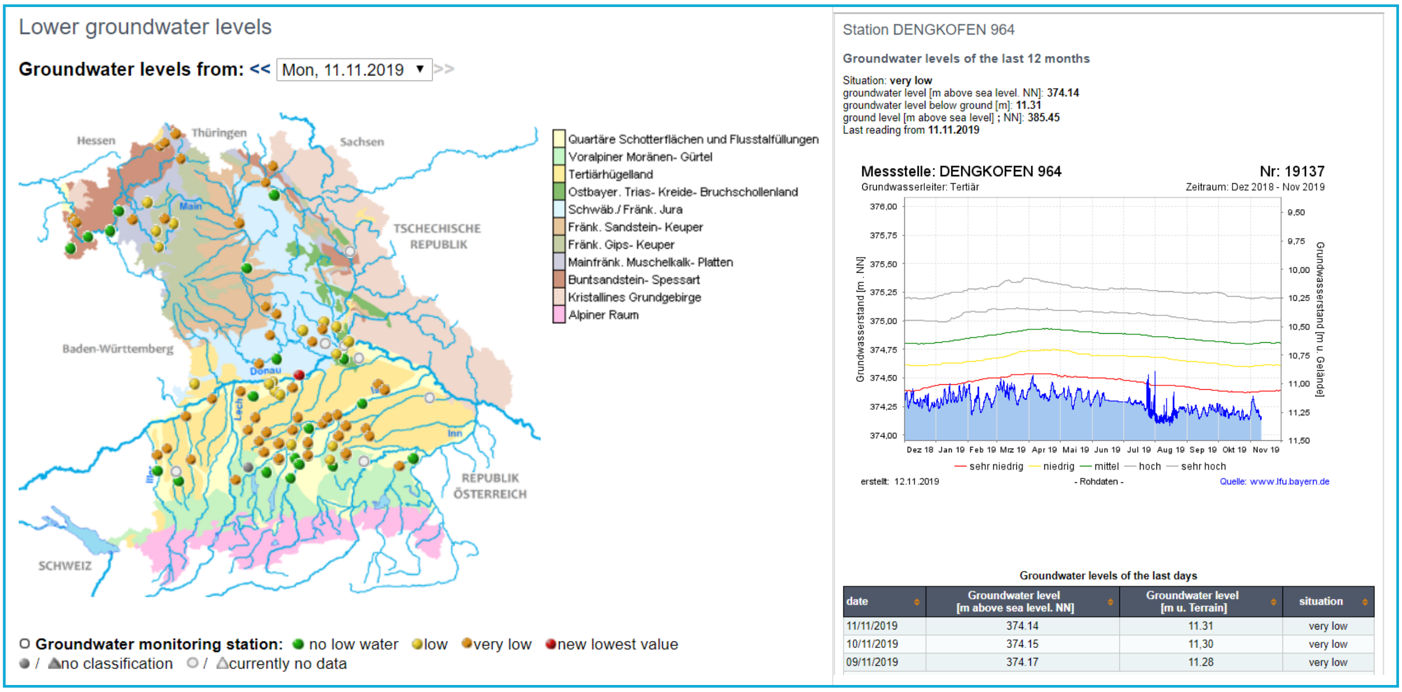
Values for each well are classified in new lowest value (or level), very low, low, no low water, no classification, and currently no data. This classification is based on a statistical analysis of the available data which is carried out only at measuring points with more than 5 years of measurements available. The statistical limits are calculated for a 31-day moving period to account for natural, seasonal variations in the water levels.

- No low water (kein Niedrigwasser): current value belongs to the highest 25% of previous values (higher than 75-percentile);
- Low (niedrig): current value is lower than the 75% of previous values (less than 25-percentile);
- Very low (sehr niedrig): current value is lower than 90% of previous values (less than 10-percentile);
- New lowest value (neuer Niedrigstwert): current value is lower than the lowest value documented up to that point in time.



date	Groundwater level [m above sea level. NN]	Groundwater level [m u. Terrain]	situation
10/11/2019	400.64	33.66	new lowest value
09/11/2019	400.64	33.66	new lowest value
08/11/2019	400.65	33.65	very low

Fig. 106 - Classified groundwater monitoring sites for the shallow aquifer with time-series from the station LUEGLAS BT-W3. Source: www.nid.bayern.de/grundwasser



date	Groundwater level [m above sea level. NN]	Groundwater level [m u. Terrain]	situation
11/11/2019	374.14	11.31	very low
10/11/2019	374.15	11,30	very low
09/11/2019	374.17	11.28	very low

Fig. 107 - Classified of groundwater monitoring sites for the deep aquifer with time-series from the station DENGKOFEN 964. Source: www.nid.bayern.de/grundwasser

Sources

- **Bavarian Environment Agency, groundwater level** - https://www.lfu.bayern.de/wasser/grundwasserstand/index.htm;
- **Feedback from the Bavarian Environment Agency** - received on 17-04-2020;
- **Low water information service Bavaria, groundwater** - https://www.nid.bayern.de/grundwasser; and
- **State Geological Surveys of Germany** - https://www.infogeo.de/Infogeo/EN/Startseite/startseite_node_en.html.

Greece

Capital city: Athens
Inhabitants: 10 Million

INSTITUTIONAL SETTING AND PURPOSE

The Special Secretariat for Water under the Greek Ministry of Environment and Energy is in charge of the National Monitoring Programme of Greece. Regarding groundwater, the Institute of Geology and Mineral Exploration (IGME) has been the main promoter of the programme since 2000. The National Monitoring Network has been active since 2012.

In addition, each of the 14 prefectures of Greece have their own monitoring programmes through private boreholes.

CHARACTERISTICS OF THE NETWORK

The National Monitoring Network operates 1392 stations dedicated to groundwater quality and quantity in the main groundwater bodies of the country. Stations are divided in two categories: surveillance and operational stations. While surveillance stations monitor water bodies of good status only during a certain period, operational status stations continuously monitor water bodies that failed at achieving good status.

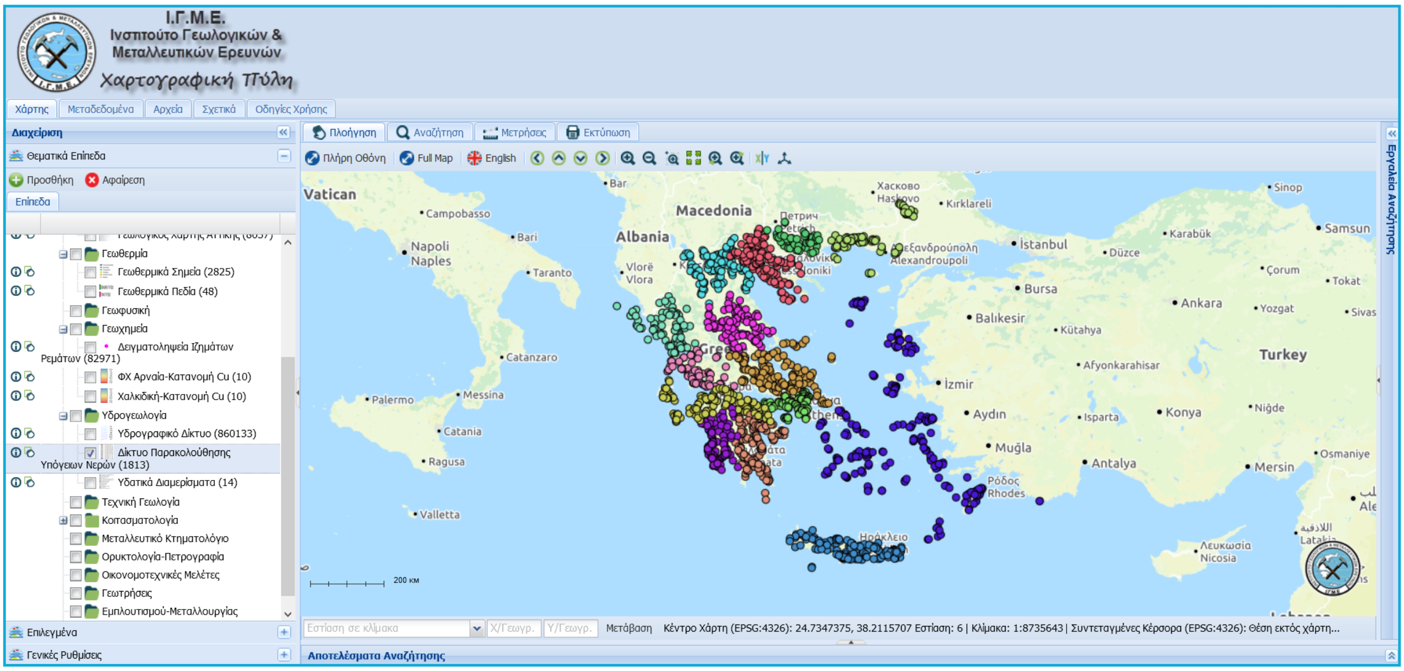


Fig. 108 - Groundwater monitoring network. Source: National Mineral Exploration Research Centre Geoportal

PROCESSING AND DISSEMINATION

Data can be found in several sources, for instance, in the National Data Bank of Hydrological and Meteorological Information (NDBHMI) and in the website and map portal of the National Water Monitoring Network. One product available in this portal are the boundaries and characterisation of groundwater bodies (GWB) per River Basin District, developed in the framework of River Basin Management Plans under the EU WFD, depicting the quantitative and qualitative status of groundwater bodies.

Monitoring data can be obtained directly via the website, but can also be requested via the Special Secretariat for Water. In addition, data from the 14 prefectures of Greece can be obtained through their water resources directorates.

The geoportal of the National Mineral Exploration Research Centre also provides open geospatial data and services for Greece, and data can be obtained from here via request. It is noteworthy that, in general, all official data can be found in the National Geodata Portal as well.

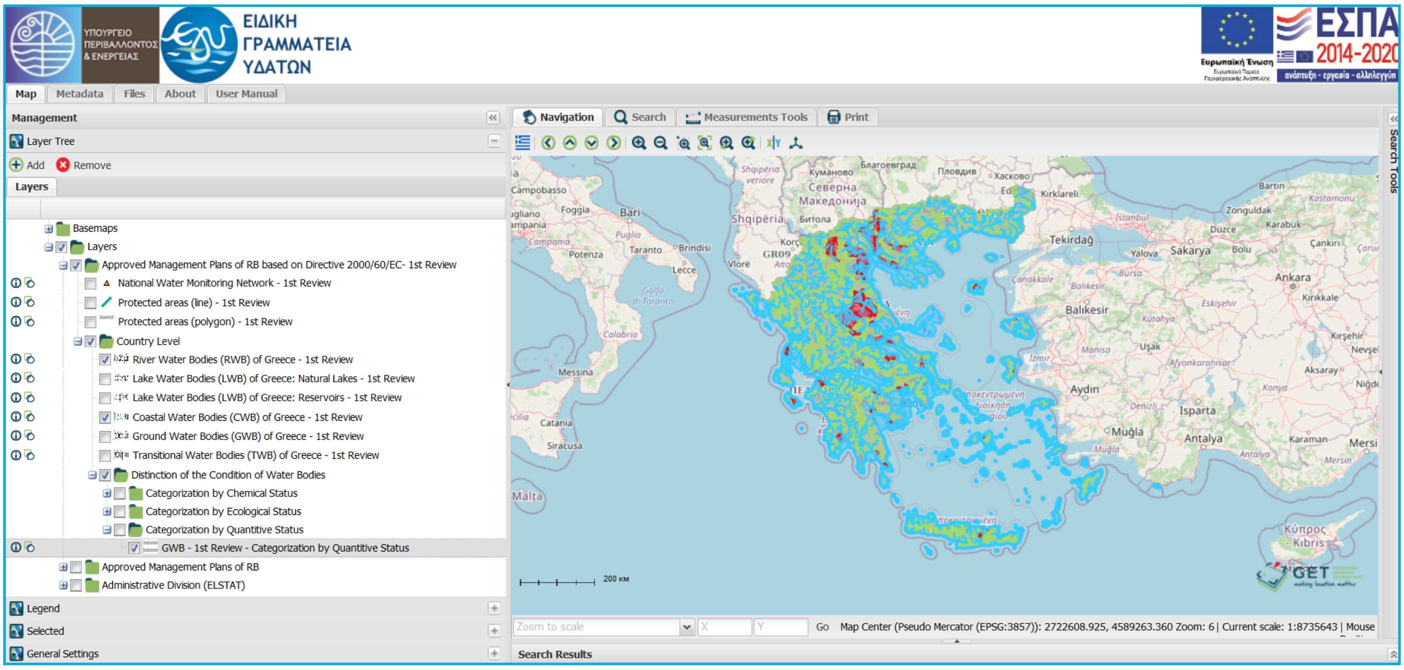


Fig. 109 - Quantitative status of groundwater bodies. Source: National Water Monitoring Network, map portal

Sources

- **Feedback from Dr. Emmanouil Varouchakis, PhD geostatistics, School of Environmental Engineering Technical University of Crete, Greece** - varuhaki@mred.tuc.gr;
- **Panteli N.-M. and Theodossiou N., 2016. Analysis of groundwater level measurements - Application in the Moudania aquifer in Greece. Available in** - http://www.ewra.net/ew/pdf/EW_2016_55_07.pdf;
- **Ministry of Environment and Energy** - https://ypen.gov.gr/;
- **National Data Bank of Hydrological and Meteorological Information (NDBHMI)** - http://ndbhmi.chi.civil.ntua.gr/en/index.html;
- **National Geodata Portal** - http://geodata.gov.gr/maps/?package=42b085a2-d390-4bd4-a9a0-6f1b3ec2ee9b&resource=646ab5b9-71ed-4b35-934f-78eec37978d1&locale=el;
- **National Mineral Exploration Research Centre Geoportal** - https://www.igme.gr/geoportal/?lang=gr;
- **National Network for the Monitoring of water status – Groundwater Monitoring Stations** - http://geodata.gov.gr/en/dataset/ethniko-diktuo-parakoloutheses-tes-katastases-ton-udaton--stathmoi-sta-upogeia-udata/resource/306aeda1-e7bc-4f99-88c0-7ade3c1d7007?inner_span=True;
- **National Water Monitoring Network** - http://nmwn.ypeka.gr/?q=en/content/national-monitoring-network**;**
- **National Water Monitoring Network, map portal** - http://wfdgis.ypeka.gr/?lang=EN;
- **National Water Monitoring Network, groundwater data** - http://nmwn.ypeka.gr/?q=groundwater-stations;
- **Report on the implementation of the Water Framework Directive River Basin Management Plans** - https://ec.europa.eu/environment/water/water-framework/pdf/4th_report/Greece_CORRECTED_5_EN_autre_document_travail_service_part1_v5-1_FINAL.pdf;
- **River Basin Management Plans** - http://wfdver.ypeka.gr/en/home-en/ and http://wfdver.ypeka.gr/en/management-plans-en/; and
- **Special Secretariat for Water, contact information to request data** - http://wfdver.ypeka.gr/en/contact-en/.

Hungary

Capital city: Budapest
Inhabitants: 9 Million

INSTITUTIONAL SETTING AND PURPOSE

The General Directorate of Water Management (OVF) is a central government body under the direction and supervision of the Ministry of Interior. It supervises, coordinates and controls the activities of the water directorates.

The National Hydrographic Monitoring Network contains data on surface water and groundwater, as well as precipitations, snow cover and soil moisture. It has been designed to provide national and local overviews, and an input for prognoses. The collection and assessment of the data are carried out by the regional water management directorates, coordinated by the OVF. The data are measured and processed according to uniform principles.

CHARACTERISTICS OF THE NETWORK

The deep groundwater monitoring network (deeper than 20 m) contains around 550 monitoring stations, while the shallow groundwater network (not deeper than 20 m) contains more than 1500 monitoring stations.

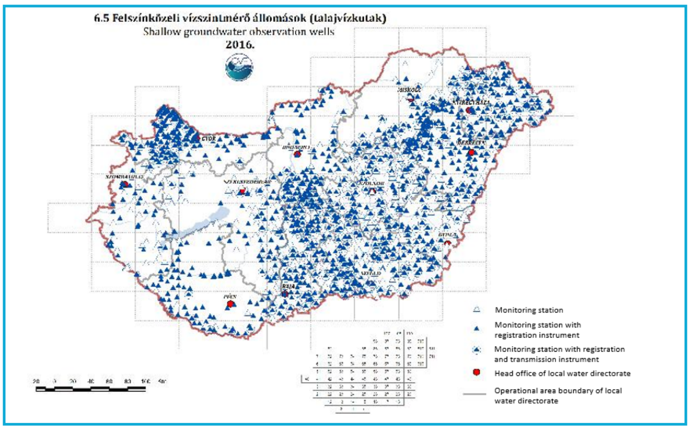


Fig. 110 - Shallow groundwater observation wells. Source: OVF

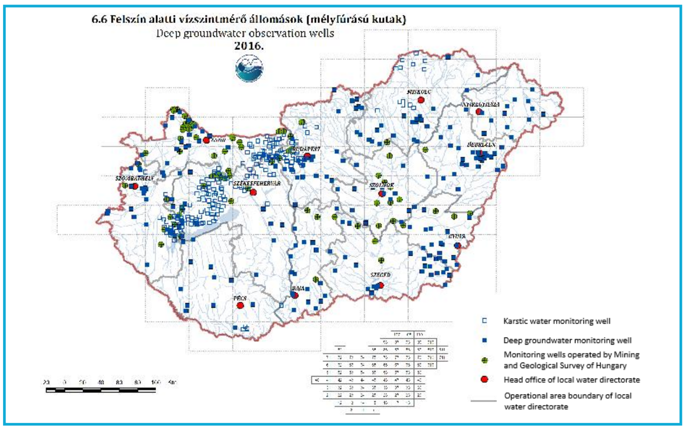


Fig. 111 - Deep groundwater observation wells. Source: OVF

PROCESSING AND DISSEMINATION

The National Adaptation Geo-information System (NAGiS) is a platform created to facilitate the policy-making, strategy-building and decision-making process necessary to improve climate change adaptation measures in Hungary. The NAGiS is a source of information on the climate trends of Hungary. The NAGiS GeoDat is a web-application where groundwater level data are shown in a table or a graph format. Data are available in Hungarian for registered users.

Moreover, the Hydrographic Yearbook of the hydrographical service of Hungary, first published in 1887, consist of hydrographic measurements as well as the most important data describing hydrological and hydrometeorological conditions, including a summary introducing the hydrological and hydro-meteorological events and characteristics of the given year. Tables containing daily data of karstic and groundwater levels (shallow and deep) are provided. The spatial location of monitoring networks is shown in thematic maps.

Sources

- **Feedback from OVF** - received on 25-03-2020;
- **Hydrographic Yearbooks** - https://www.vizugy.hu/print.php?webdokumentumid=1524;
- **Hungarian General Directorate of Water Management (OVF)** - http://www.ovf.hu/en/vizugy-tortenet-en;
- **OVF, Hydrographic monitoring** - http://www.ovf.hu/hu/vizrajzi-monitoring; and
- **NATER Project, NaGIS web application** - https://nater.mbfsz.gov.hu/hu/user/login?destination=cas/login.

Ireland

Capital city: Dublin
Inhabitants: 4 Million

INSTITUTIONAL SETTING AND PURPOSE

The Environmental Protection Agency (EPA) of Ireland manages the Groundwater Monitoring Programme, following the Article 8 of the Water Framework Directive (WFD). The purpose of the Network is to assess the general status of groundwater quality and levels in the Republic of Ireland to protect the source for public and private drinking water supplies and associated surface water and ecological receptors. Additional groundwater monitoring is carried out by the local authorities, academic research institutions, private consultants and the Geological Survey of Ireland.

CHARACTERISTICS OF THE NETWORK

The groundwater level monitoring network is focused on groundwater bodies that are considered "at risk" from depletion due to over-abstraction, which are very few in Ireland. Its purpose is to help assess how groundwater levels and flows to surface water receptors are affected by groundwater abstractions. At the moment, the network has 126 active monitoring stations.

Other monitoring networks are dedicated to "not at risk" groundwater bodies with the purpose of helping to improve the conceptual understanding of the flow of groundwater.

Both wells and springs are part of the groundwater monitoring network. In wells, the groundwater level is measured using a combination of data loggers and manual dipping. Discharge from springs is generally measured using water level/flow rating curve relationships, with ultrasonic flow measurement devices at some sites. At some other spring sites, stop flows are measured using flow meters without continuous flow measurement. Where there is no continuous water level (and stage-discharge rating curves) or velocity measurements at springs, single spot flow measurements are taken, i.e. the flow is measured at the time of the water quality sample to calculate chemical loads from the springs.

The EPAHydroNet portal shows the location of the groundwater levels monitoring stations, and time series data, which is also available for downloading, figure on next page.

As groundwater abstractions are typically not a significant issue in Ireland (~80% of the volume of water comes from surface water), groundwater levels are not something EPA extensively monitor.

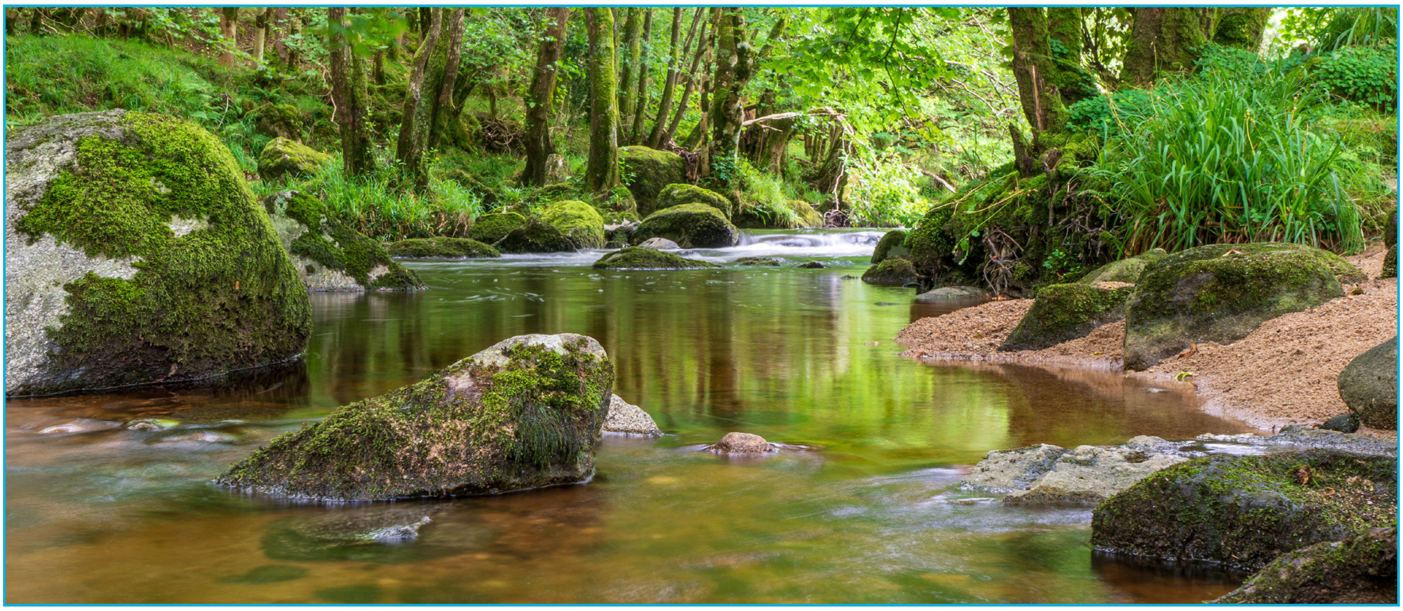


Fig. 112 - Glencree River slow moving through green trees

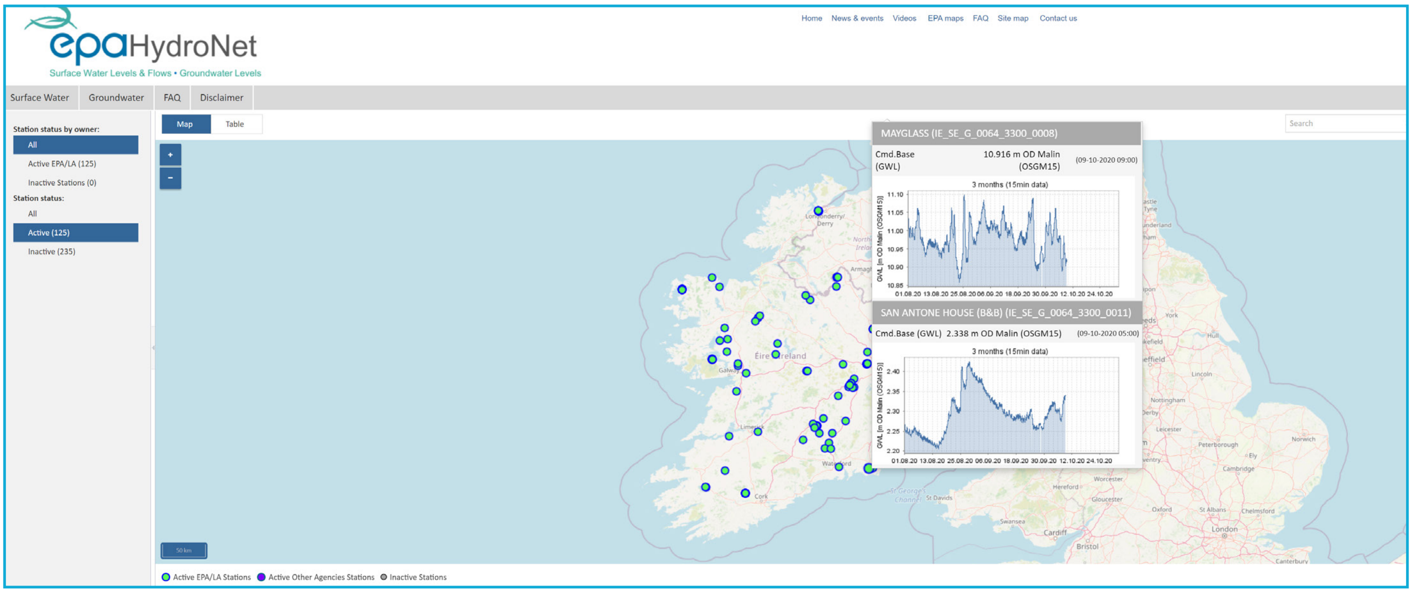


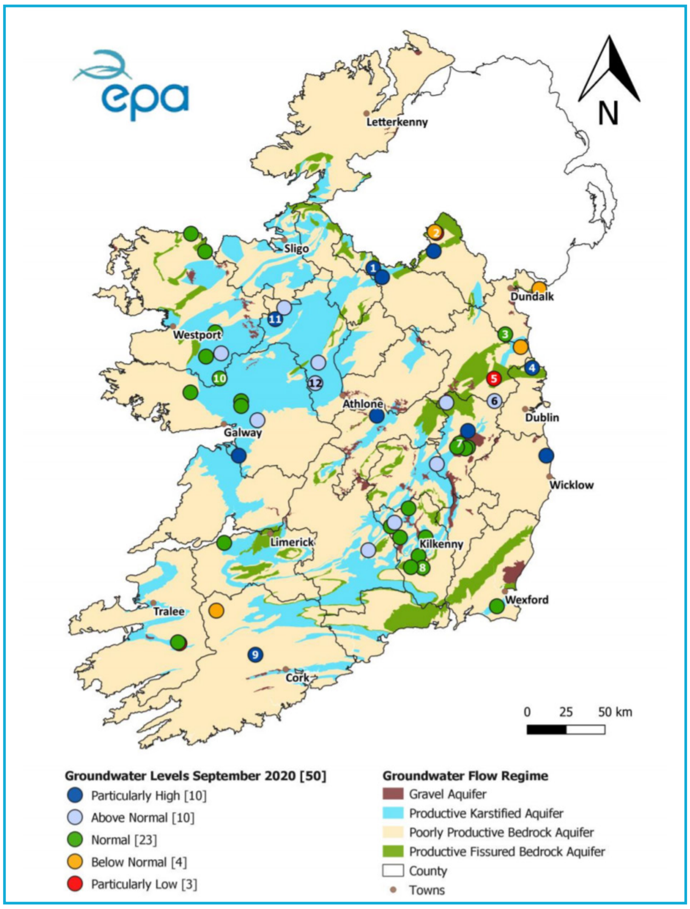
Fig. 113 – EPAHydroNet web portal

PROCESSING AND DISSEMINATION

Groundwater level data is used to support WFD assessments. Separate to this, EPA just completed water resource and abstraction impact assessments for groundwater and surface water, and material relating to this will be going on the official website later on this year.

EPA is also developing a 1-page water bulletin, that graphically/visually shows how groundwater levels, river flows and lake levels are relative to the seasonal averages and 95%iles. EPA completed the work and is in the process of preparing them for online publication; the aim being to have monthly bulletins.

Fig. 114 – Groundwater levels reported in September 2020, source: EPA Water Bulletin



Sources

- **Environmental Protection Agency (EPA), groundwater level monitoring** - http://www.epa.ie/water/wm/groundwater/level;
- **EPA HydroNet, groundwater levels** - http://www.epa.ie/hydronet/#Groundwater; and
- **Feedback from EPA** - received on 20-03-2020.

Italy

Capital city: Rome
Inhabitants: 60 Million

INSTITUTIONAL SETTING AND PURPOSE

The Italian Institute for Environmental Protection and Research (ISPRA) acts under the Italian Ministry for the Environment and the Protection of Land and Sea (MATTM). It was established in 2008 as a result of integration of the Agency for Environment and Technical Services (APAT), the Institute for Marine Environmental Research (ICRAM) and the Institute for Wild Fauna (INFS). ISPRA is composed of 20 Regional and 2 Provincial Environmental Agencies (named ARPAs and APPAs, respectively) and links the knowledge and experience of local environmental issues with national and European policies.

ISPRA's one of the main activities is data collection and validation of the National Environmental Information System (SINA).

The groundwater monitoring network in Italy is not centralized and consists of a group of regional groundwater monitoring networks that are managed by ARPAs. An example of Piedmont groundwater monitoring network is described below.

CHARACTERISTICS OF THE NETWORK

Piedmont Regional Groundwater Monitoring Network (RMRAS) has 605 wells (data from 2012) most of them private and measured manually.

There are 119 piezometers where water level is measured automatically. 116 wells are used for qualitative monitoring as well.

PROCESSING AND DISSEMINATION

The piezometric reference level in the RMRAS is represented by the range of fluctuation between the 1st and 3rd quartiles of monthly long-term average values (9-15 years). The range is considered as the natural annual fluctuation of the groundwater in that given piezometer of the network. Values of the piezometric level below 15-30% of the reference level are considered critical conditions for the quantitative state of the water body.

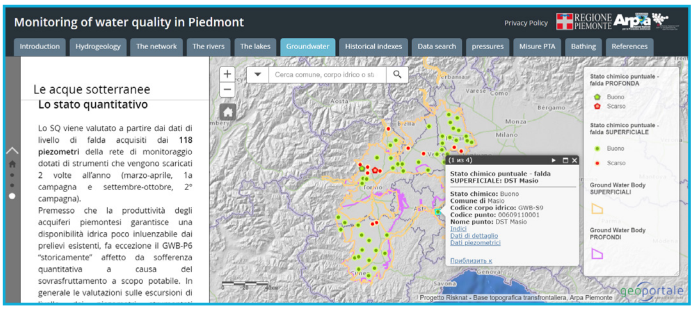


Fig. 115 – Piedmont groundwater monitoring web portal. Source: ARPA Piemonte

The data from the Network is available on the Piedmont ARPA web portal. When a user selects an observation point, a pop-up window appears with the possibility to see the depth to the groundwater level and its long-term fluctuation, Figure 115 and Figure 116.

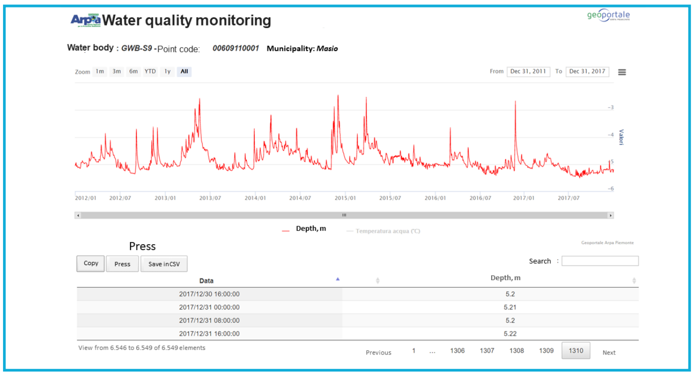


Fig. 116 – Groundwater level fluctuation time-series. Source: ARPA Piemonte

Sources

- **Regional Agency for Environmental Protection (ARPA) of Piemonte. Groundwater monitoring network** - http://www.arpa-piemonte.it/approfondimenti/temi-ambientali/acqua/rete-di-monitoraggio/rete-di-monitoraggio-delle-acque-sotterranee;
- **ARPA of Piemonte, water resource analysis** - http://www.arpa.piemonte.it/approfondimenti/temi-ambientali/idrologia-e-neve/idrologia-ed-effetti-al-suolo/documenti-e-dati/rapporto-situazione-idrica-piemontese.

Latvia

Capital city: Riga
Inhabitants: 1.9 Million

INSTITUTIONAL SETTING AND PURPOSE

The Latvia Environment, Geology and Meteorology Centre (LEGMC, www.meteo.lv/en/) is in charge of the state groundwater monitoring network. Its objective is to provide data on long-term state and trends of groundwater in the country, and input for national water policy planning, regulatory agencies and the public. Specific objectives of groundwater monitoring in Latvia are:

1. assessing quantitative and qualitative status of groundwater resources and the impact of various sources of pollution,
2. developing river basin management plans and measures for a rational use of groundwater resources, and
3. assessing the effectiveness of measures taken.

CHARACTERISTICS OF THE NETWORK

The network covers the whole territory of Latvia and provides observations from all exploited water horizons (aquifer system layers), focusing on the layers which are mainly used for water supply. The largest density of network is in Rīga, Jūrmala and Liepāja, the cities with the highest groundwater extraction rate and with the most potential sources of groundwater contamination. The groundwater level observation network consists of 305 wells distributed over 60 stations.

Data on groundwater quantity and quality are collected both manually and automatically (data loggers and automatic transmission). 197 wells distributed in 41 stations are equipped with automatic loggers measuring the level every day. In the case of manual observations, the frequency ranges from once a month to four times a year, depending on the aim of monitoring.

PROCESSING AND DISSEMINATION

The evaluation is based on large-scale and long-term observation datasets. Time series analysis, spatial interpolation and statistical analysis are used to process the data. On the LEGMC website, it is possible to download groundwater monitoring data and statistically processed information, figure 117. The Data Accessibility tool provides info on kind of observation that can be found at each station whereas the Data Search tool has a data download option as well. The results of long-term and not-digitalized observations can be requested from the Environmental Data Archive (also a part of the LEGMC).

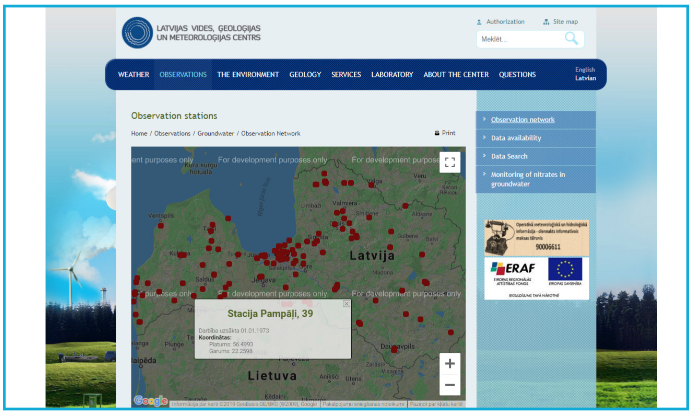


Fig. 117 – Location of observation points from LEGMC website

Sources

- **Feedback from LEGMC** - received on 27-05-2020;
- **Feedback from LEGMC (answer to form)** - received in 2018;
- **Latvian Environment, Geology and Meteorology Centre. Monitoring stations** - https://www.meteo.lv/pazemes-udens-staciju-karte/?&nid=474;
- **Latvian Environment, Geology and Meteorology Centre. Groundwater** - https://www.meteo.lv/lapas/noverojumi/pazemes-udens/pazemes-udens_ievads?id=1330&nid=473;
- **Latvian Environment, Geology and Meteorology Centre. Data Search** - http://www.meteo.lv/pazemes-udens-datu-meklesana/?nid=475; and
- **Latvian Environment, Geology and Meteorology Centre. Data availability** - https://www.meteo.lv/pazemes-udens-datu-pieejamiba/?&nid=476.

Lithuania

Capital city: Vilnius
Inhabitants: 2.8 Million

INSTITUTIONAL SETTING AND PURPOSE

The Ministry of Environment (MoE) is in charge of water resources management in Lithuania. The Lithuanian Geological Survey (LGS) under the MoE implements the EU Water Framework Directive related to groundwater and manages its monitoring, classifies the status of groundwater bodies and establishes objectives for groundwater bodies. Additionally, groundwater monitoring in Lithuania is carried out in accordance with the State Environmental Monitoring Program. The network is focused on determining the state and trends on groundwater quantity and quality. It includes groundwater level measurements and groundwater sampling for laboratory analysis.

CHARACTERISTICS OF THE NETWORK

The quantitative groundwater monitoring network in Lithuania consists of 76 observation wells. Measurements of the groundwater level and temperature are performed daily. The measurements are collected twice a year and processed by the Geological Survey.

The majority of groundwater quantitative monitoring stations are installed in shallow aquifers (60 wells), which are sensitive to the change in meteorological conditions.

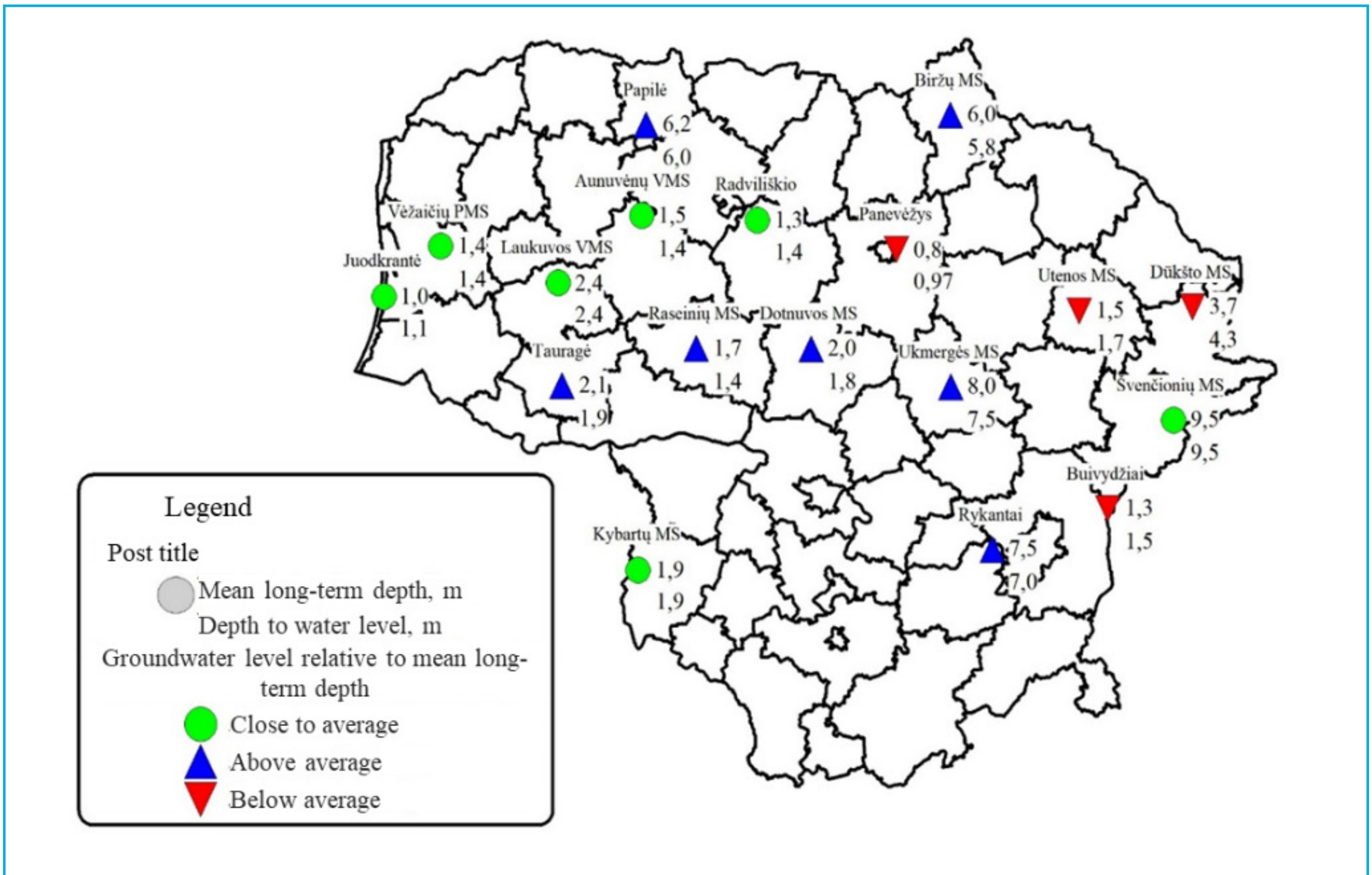


Fig. 118 - Groundwater levels in 2017 in comparison with levels from 2006-2017 period

PROCESSING AND DISSEMINATION

National Groundwater Monitoring Statistics is available at the LGS website (https://www.lgt.lt/) based on monitoring data from 1990 till 2018. The information can be grouped by counties, districts, municipalities, river basins and aquifers.

Limited data from the observation wells is available on the web portal of the LGS, figure 119. When selecting an observation point, a user gets the code, name and type of the well with XY coordinates, monitoring type, measured parameters and the name of an aquifer.

Apparently, data from the National Groundwater Monitoring Network are accessible by logging in as a Lithuanian resident, business entity or public sector through the E-Government Gateway.

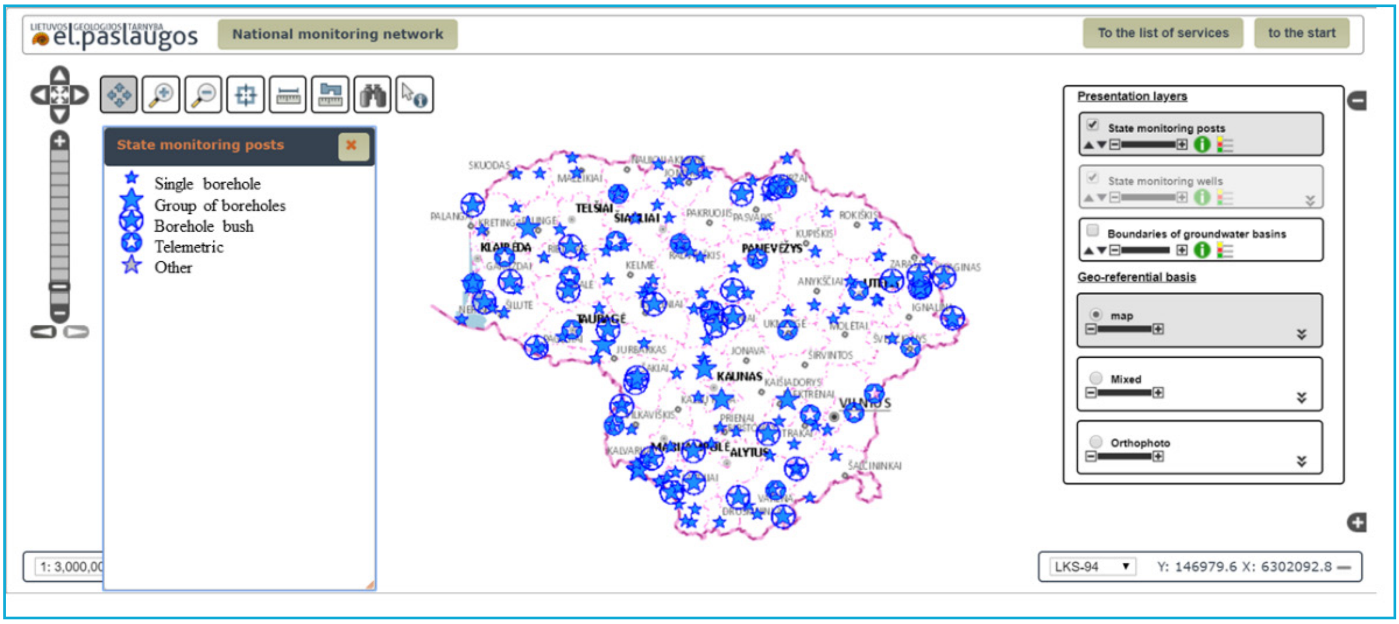


Fig. 119 - National monitoring network in Lithuania. Source: LGS web portal

Sources

- **Food and Agriculture Organization of the United Nations (FAO) AQUASTAT, 2016** - http://www.fao.org/aquastat/en/countries-and-basins/country-profiles/country/LTU;
- **Groundwater Information System (PozVIS)** - https://www.lgt.lt/epaslaugos/index.xhtml;
- **Lithuanian Geological Survey** - https://www.lgt.lt/; and
- **Lithuanian Geological Survey. Exploration** - https://www.lgt.lt/index.php?option=com_content&view=article&id=156&Itemid=1265&lang=lt.

Luxembourg

Capital city: Luxembourg City
Inhabitants: 0.6 Million

INSTITUTIONAL SETTING AND PURPOSE

The Administration of Water Management, under the Ministry of Environment, Climate and Sustainable Development, is in charge of groundwater monitoring in Luxembourg in accordance with the European Water Framework Directive. One of the missions of the Administration is to monitor and control the application of legal and regulatory requirements for water management including surface and groundwater.

CHARACTERISTICS OF THE NETWORK

Currently, there are seven operational monitoring stations in the network which register groundwater level and temperature.

PROCESSING AND DISSEMINATION

Geoportal.lu is Luxembourg official national geoportal. It is a platform for collection, description, visualisation and dissemination of geospatial data and related products, figure 120. The Administration of Cadastre and Topography (the national cadastre and mapping authority) developed the portal.

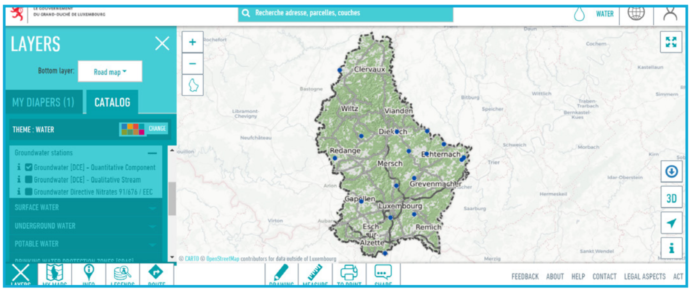


Fig. 120 - Geoportal with quantitative groundwater monitoring points

Reports (that include location details, constructive details, geological maps, photos and quality analysis for several parameters) are provided for each monitoring station, figure 121.

Fig. 121 - Documentation for measuring points on the Geoportal

Some data on groundwater abstraction are available as well. The Administration of Water Management publishes bulletins on the quantitative situation of groundwater in the country.

Sources

- **National official geoportal** - https://www.geoportail.lu/en;
- **General maps of the National official geoportal** - https://map.geoportail.lu;
- **Quantitative situation of groundwater** - https://eau.public.lu/eaux_souterraines/Situation-quantitative-des-eaux-souterraines/index.html; and
- **Quantitative data groundwater** - https://data.public.lu/en/datasets/quantitative-data-groundwater.

Moldova

Capital city: Chisinau
Inhabitants: 3.5 Million

INSTITUTIONAL SETTING AND PURPOSE

The State Enterprise Hydro-Geological Expedition from Moldova, a state organisation under the Ministry of Agriculture, Regional development and Environment, carries out the Groundwater Monitoring project at the territory of the Republic of Moldova. The objective of this project is to study groundwater systems and determine physical and chemical trends in groundwater due to natural factors with the final goal to protect the resource from pollution and overexploitation.

CHARACTERISTICS OF THE NETWORK

The Republic of Moldova started regular groundwater monitoring activities in 1960. The national groundwater network has currently 33 stations, figure 122. The frequency of monitoring varies from 1 to 10 times a month. Temperature is measured together with water levels. For a limited amount of points, chemical analysis is done 2 times a year, for the rest once a year.

PROCESSING AND DISSEMINATION

Information on the aquifer systems and horizons of the Artesian Moldavian Basin (which belongs to the Artesian Black Sea Basin and includes the whole territory of Moldova) can be found in the State Enterprise Hydro-Geological Expedition from Moldova website. Periodical reports on the state of groundwater levels can be found at the Enterprise, which are accessible via request.

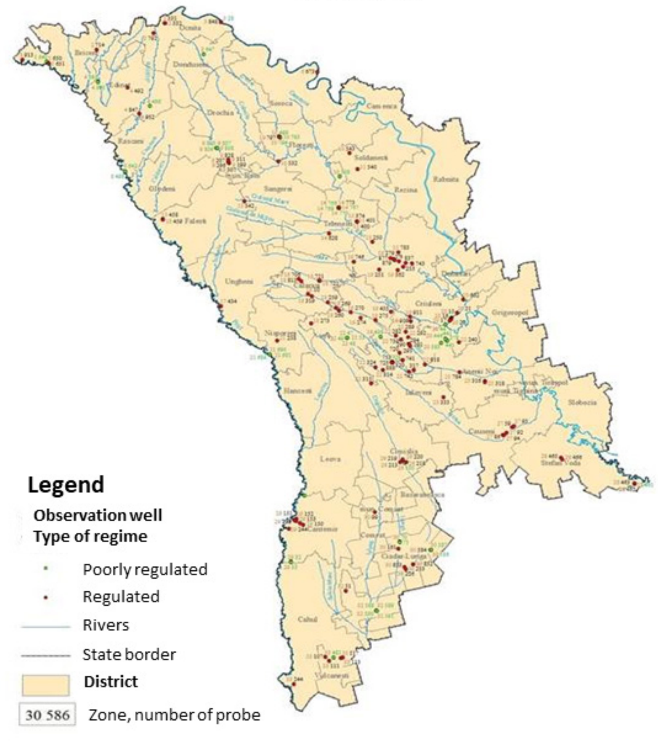


Fig. 122 – Location of observation wells in the Republic of Moldova. Source: The State Enterprise Hydro-Geological Expedition from Moldova

Sources

- **Feedback from the State Enterprise Hydro-Geological Expedition from Moldova -** received on 24-06-2020;
- **State Enterprise Hydro-Geological Expedition from Moldova** - http://www.ehgeom.gov.md/en;
- **State Enterprise Hydro-Geological Expedition from Moldova, groundwater monitoring** - http://www.ehgeom.gov.md/en/proiecte-din-bugetul-de-stat/monitorizarea-apelor-subterane; and
- **Ministry of Agriculture, Regional Development and Environment, Government of the Republic of Moldova** - http://www.madrm.gov.md/ro/content/acte-departamentale.

The Netherlands

Capital city: Amsterdam
Inhabitants: 17.3 Million

INSTITUTIONAL SETTING AND PURPOSE

The Ministry of Infrastructure and Water Management is in charge of the national groundwater monitoring programme in the Netherlands. Groundwater monitoring networks are managed on a national, regional and local levels. Provincial authorities and water boards take up the responsibility at the regional level, and municipalities and water supply companies are in charge of the groundwater monitoring at the local level. The establishment of the monitoring network started in 1970 with a goal to provide insights into the spatial distribution of hydraulic heads per aquifer.

CHARACTERISTICS OF THE NETWORK

The primary groundwater level monitoring network is developed and maintained by 11 provinces. In the past, the network used to measure the groundwater level every 14 days, but now data loggers collect it every hour. Total number of sites are 1,000 with 49,000 monitoring wells, 74,000 piezometers and 130 million groundwater levels/heads, figure 123.

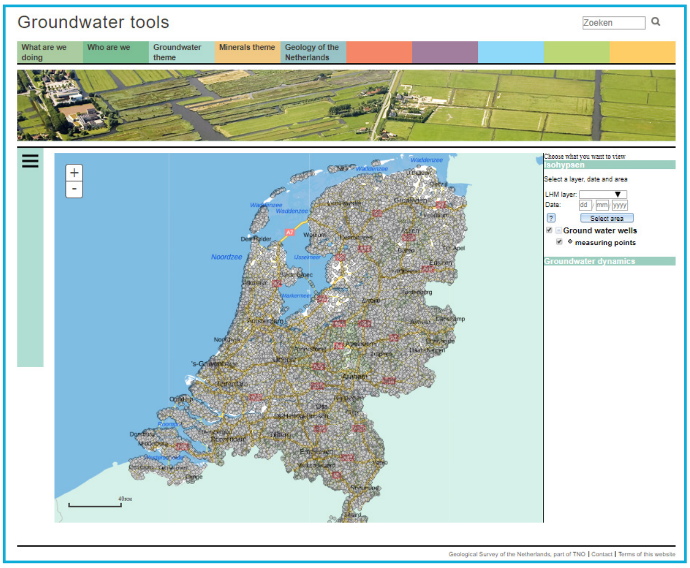


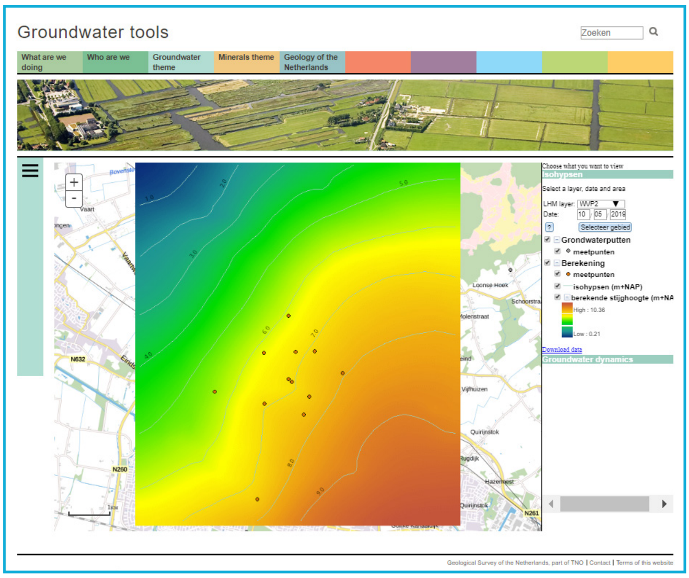
Fig. 123 -Groundwater monitoring points in the Netherlands. Source: Grondwatertools viewer

The information on quantity and quality of the groundwater in the Netherlands can be accessed through DINOloket. The data are currently supplied in a format that the user can easily view in a spreadsheet (Excel format). However, a limited amount of data are currently being offered.

Grondwater Tools is an interactive portal designed to share information about groundwater in the Netherlands. The Groundwater Tool viewer allows the user to visualize the locations of monitoring wells in the Netherlands and use two powerful analysis tools: Contour lines (Isohypsen) and Groundwater Dynamics (Groundwaterdynamiek).

Contour lines

Contour lines are the lines with the same groundwater level on a map. They show the spatial pattern of levels and help to understand the direction of the groundwater flow. Grondwater Tool allows to choose for which date and in which aquifer a user want to see the contour lines, figure 124. The data are downloadable and the file includes piezometric levels (Excel format), semivariance graph, figure 124 (jpeg), Krigging results (Excel format) and contour lines (shape file). The contour lines are calculated based on rising ranges (groundwater levels) from the DINOloket, the NHI (Dutch Hydrological Instrumentation) and 3.0 hydraulic heads from the Deltares.



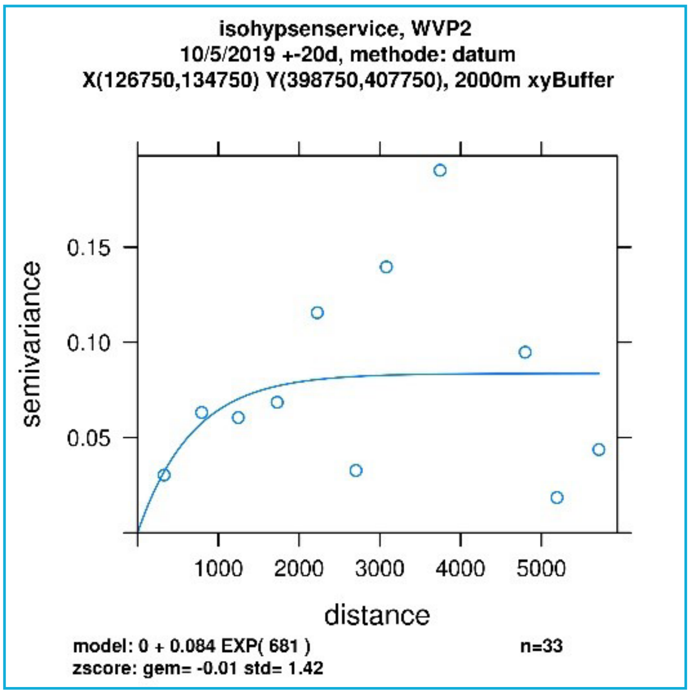


Fig. 124 - Contour lines for Leikeven area, Tilburg, the Netherlands (previous page) – Grondwatertools viewer (above) – semivariance for groundwater levels from the selected area

Groundwater Dynamics

The system makes use of a transfer function-noise model with precipitation and evaporation as independent variables. An automated quality control is performed through a several steps in order to filter out time series that do not comply with the following criteria:

- Observations provide enough information about groundwater dynamics (enough amount of measurements in a long time period);
- Time series do not have a high number of errors (outliers, steps, drift);
- Small effect from other influences than precipitation and evaporation; and
- Linear behaviour of the groundwater system.

The three levels of model results are presented:

1. Groundwater levels time-series and associated statistics;
2. Components of time-series that can be explained by precipitation and evaporation; and
3. Regime curve based on at least 20 years simulation with the time-series model.

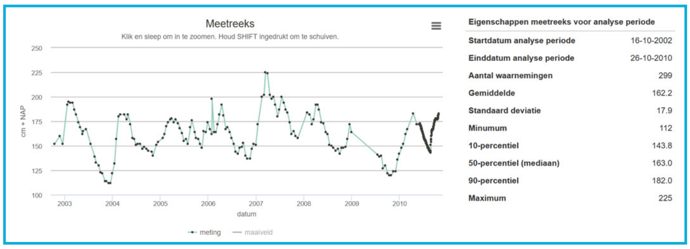


Fig. 125 - Level 1 for one monitoring well. Source: Grondwatertools viewer

For Level 1 no specific criteria are used for the further interpretation. Statistics includes the average, standard deviation, maximum, minimum, and the percentiles 10, 50 and 90, figure 125.

Level 2 presents the result of the time-series modelling, requiring automated evaluation of the model results. Two sets of criteria are defined:

1. The first set of criteria assess the length and number of observations of the dataset;
2. The second set of criteria evaluates the model output. This step will be performed only if the first set of criteria is satisfied.

Level 3, or the regime curve, figure 126, is presented in the Grondwater Tools viewer when Level 2 is satisfied (e.g. if the calibrated time-series model is applied for the simulation). Furthermore, more criteria are added to evaluate the predictive performance of the model.

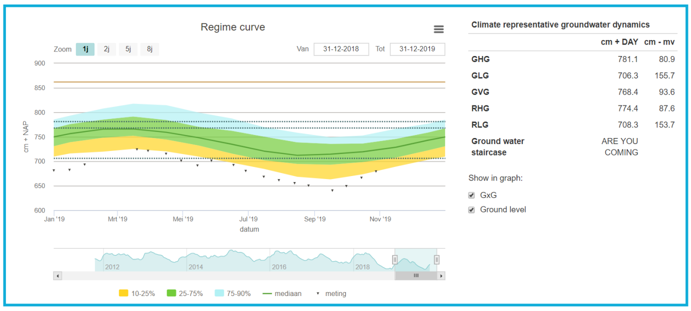


Fig. 126 - Regime curve and climate representative groundwater characteristics for one monitoring well. Source: Grondwatertools viewer

To properly calculate the influence of the annual seasonal pattern (periodicity), several years of measurements are required; characteristics of groundwater regime are automatically calculated using the last 8 years of measurements. Then, the climate-representative groundwater characteristics are simulated over a period of 20 years.

This climate-representatives are:

- GHG: Average highest groundwater levels, which occur mainly in winter and early spring;
- GLG: Average lowest groundwater levels, which usually occur in late summer;
- GVG: Average spring groundwater level;
- GxG: The data set of GHG, GLG and GxG;
- RHG: 90-percentile based on the time-series model simulated over a period of at least 20 years;
- RLG: 10-percentile based on the time-series model simulated over a period of at least 20 years; and
- Grondwatertrap (groundwater stairs/category): This value is based on the values of GHG and GLG, (Table on next page).

Grondwatertrap	GHG (cm-mv)	GLG (cm-mv)
I	<20	<50
II	<40	50-80
IIB	25-40	50-80
III	<40	80-120
IIIB	25-40	80-120
IV	>40	80-120
V	<40	>120
VI	40-80	>120
VII	>80	-
VIII	>140	-

Fig. 127 - Value ranges for groundwater categories

Groundwater Dynamics tool also provides an analysis of daily influence of precipitation and evaporation components (the distance from the shading to the explained part, figure below) on the groundwater levels.

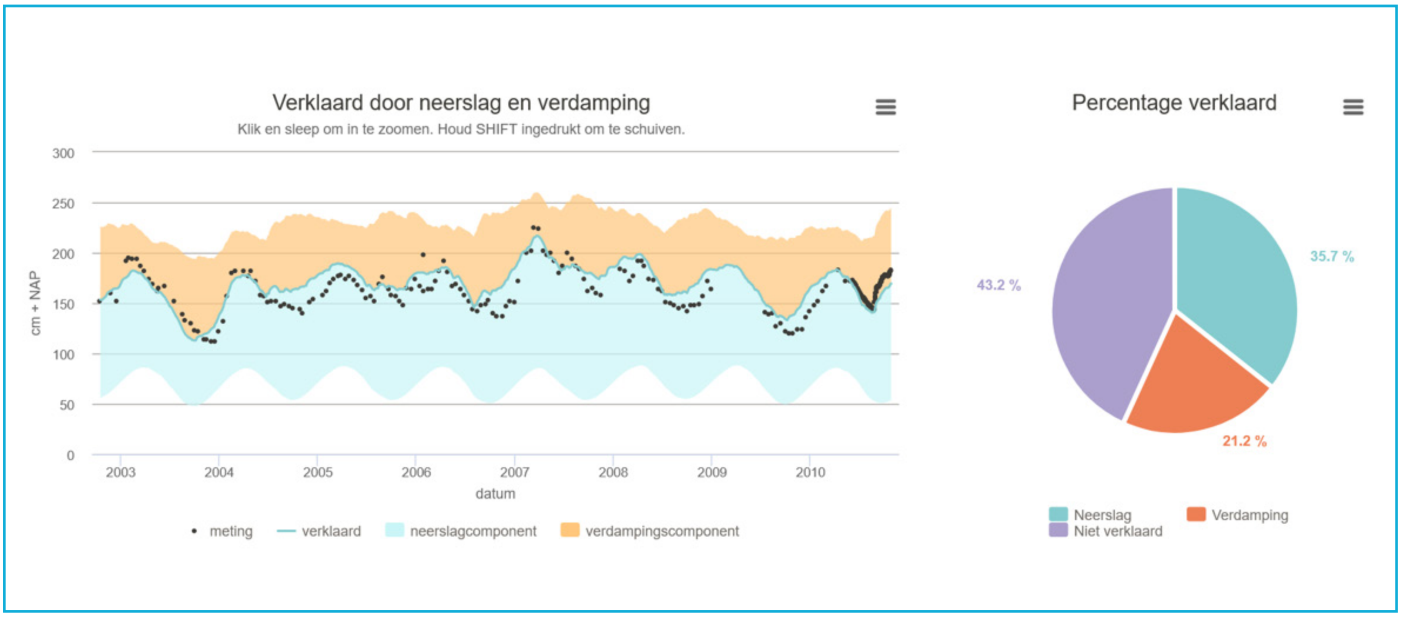


Fig. 128 - Influence of precipitation and evaporation on groundwater levels for one monitoring well. Source: Grondwatertools viewer

Sources

- **DINOloket, Data and Information of the Dutch Subsurface. Levels** - https://www.dinoloket.nl/en/levels;
- **DINOloket, Subsurface models** - https://www.dinoloket.nl/ondergrondmodellen;
- **Grondwatertools** - https://www.grondwatertools.nl;
- **Grondwatertools** - https://www.grondwatertools.nl/regis-ii-0;
- **Grondwatertools** - https://www.grondwatertools.nl/isohypsen; and
- **Grondwatertools** - https://www.grondwatertools.nl/grondwatertools-viewer.

Norway

Capital city: Oslo
Inhabitants: 5.4 Million

INSTITUTIONAL SETTING AND PURPOSE

The Norwegian Water Resources and Energy Directorate (NVE) under the Ministry of Petroleum and Energy is in charge of groundwater monitoring in Norway, especially regarding groundwater levels and temperature. The main objective of the NVE is to ensure an integrated and environmentally sound management of the country's water systems, promote efficient energy markets and cost-effective energy systems, and contribute to efficient energy use.

Groundwater monitoring system operated by the NVE is used to monitor hydrological conditions including flooding, to analyse water resources changes related to climate change and to implement the EU Water Framework Directive as well as provide flooding and landslide warnings.

CHARACTERISTICS OF THE NETWORK

The network has about 80 stations, some of them are depicted in figure 129. All groundwater stations operated by the NVE are part of the National Groundwater Network (LGN), a collaboration with the Norwegian Geological Survey (NGU). NGU is responsible for mapping groundwater resources and recording the chemical state of the groundwater.

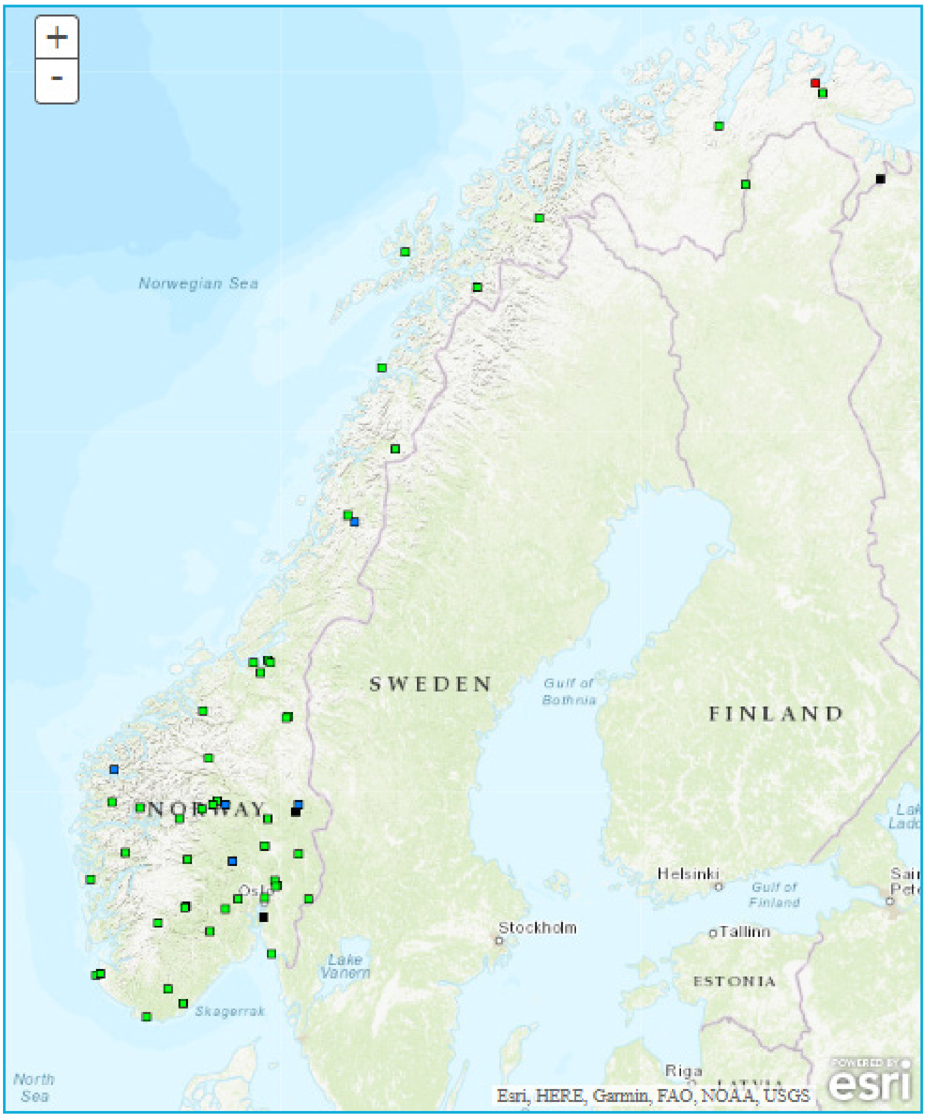


*Fig. 129 - Groundwater Monitoring Network of Norway. Source: NVE website**

** Green = updated last week*
Blue = updated last 60 days
Red = data older than last 60 days
Gray = not updated

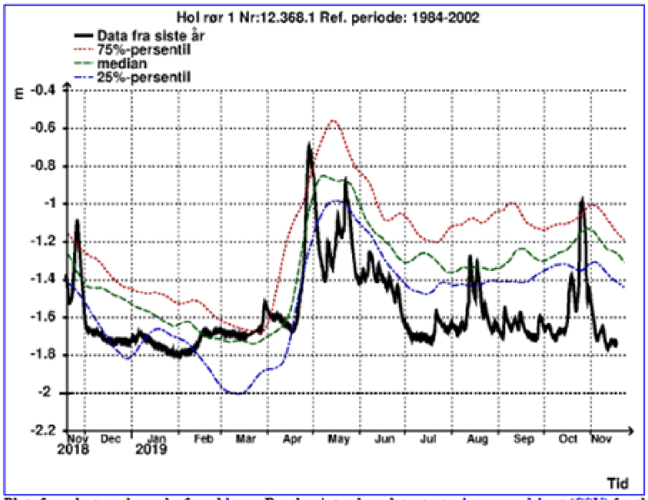
PROCESSING AND DISSEMINATION

Groundwater level data are analysed through median, 25% and 75% percentile and presented as a time series graph, figure 130. The hydrological real-time data graphs show all measurements obtained in the displayed time period.

Hence it is possible to compare the current levels with the values on the same day in previous years, the reference period is from 1984 till 2002. In the portal, there is an option to download the data in textual or spreadsheet format for the last two years.

Groundwater level - deep below ground for Hol pipes 1 No: 12.368.1

Last measurement, time = 18.11.2019 18:00, value = -1.739



Plots from last week can be found here . Breakpoint values data, textual or spreadsheet (CSV) for the last 60 days. (Reverse order, only textual).
List of plot data, textual or spreadsheet (CSV) .
List of daily data, textual or spreadsheets (CSV) . Map of the station here .

Station:	Location:
Station name:Hol tube 1	UTM zone:32
Station high:454.0	UTM east:467070
Mapleaf(N50 series):1516-II	UTM north:6715752
	Longitude:8.39913
	Latitude:60.57636
	County:Buskerud
	Municipality:Hol

Explanations of terms for the graphs. Groundwater level - deep below ground in m. Note that the percentiles are smoothed, to improve plot readability and give a more accurate picture of the normal situation. Reference period for percentiles: 1984 - 2002

Up to the groundwater level map page - deep below ground. Up to NVE's main site.
Questions about data quality and lack of specific drives can be found on the FAQ page . Other questions and messages can be sent to hydrology that nve.no .
Last updated: *19/11/2019 04:30*

Fig. 130 - Groundwater level data viewer. Source: NVE website

Sources

- **Feedback from the Norwegian Water Resources and Energy Directorate (NVE)** - received on 07-10-2020;
- **Groundwater level monitoring stations, deep wells** - http://www2.nve.no/h/hd/plotreal/GRW/index.html;
- **The Norwegian Water Resources and Energy Directorate (NVE), ground and groundwater** - https://www.nve.no/hydrologi/grunn-og-markvann/?ref=mainmenu; and
- **Geological Survey of Norway, Map viewers** - https://www.ngu.no/emne/kartinnsyn?field_temagruppe_tid=2358.

Poland

Capital city: Warsaw
Inhabitants: 38 Million

INSTITUTIONAL SETTING AND PURPOSE

The State Water Holding Polish Waters is a central administrative body responsible for water conservation, management and use. The main tasks of the Holding include development of the national water and environmental programme, keeping the water inventory country-wide, supervising the performance of the National and Regional Water Management Boards; and hydrological, meteorological and hydrogeological services.

In Poland, groundwater monitoring is carried out through national, regional and local networks. The institution responsible for the organization and coordination of monitoring studies is Chief Inspectorate for Environmental Protection.

CHARACTERISTICS OF THE NETWORK

The national network consists of selected, representative observation points.

First groundwater level monitoring in Poland began in the 1970s and quality monitoring in 1991. The network was formed to reflect specific features resulting from the unique geological structure and hydrogeological conditions in Poland. Particular attention is paid to the development of observation networks in recharge and discharge zones, as well as areas endangered by drought, flooding and degradation of groundwater quality. Since Poland joined the European Union, the organisation and scope of groundwater monitoring was adapted to comply with European Community directives and for that reason it relates to monitoring of groundwater bodies. For the current planning cycle there are 172 groundwater bodies in consideration, and there will be 174 for the cycle 2022-2027.

The depth of the water table is measured daily at so-called first order hydrogeological stations, and every Monday at the second order hydrogeological stations. The monitoring network currently comprises of ca. 1250 points (as of September 2020). In addition, 366 observation wells are equipped with automatic devices in which water level monitoring is measured every hour.

Monitoring of groundwater quality is performed within the surveillance and operational networks comprising of selected hydrogeological station of the first and second orders as well as public water supply and private wells. For the planning cycle 2016-2021 the surveillance monitoring was undertaken within ca. 1300 points and the operational in ca. 400.

Poland has also seven transboundary groundwater monitoring networks with seven neighbouring countries, with over 300 observation wells.

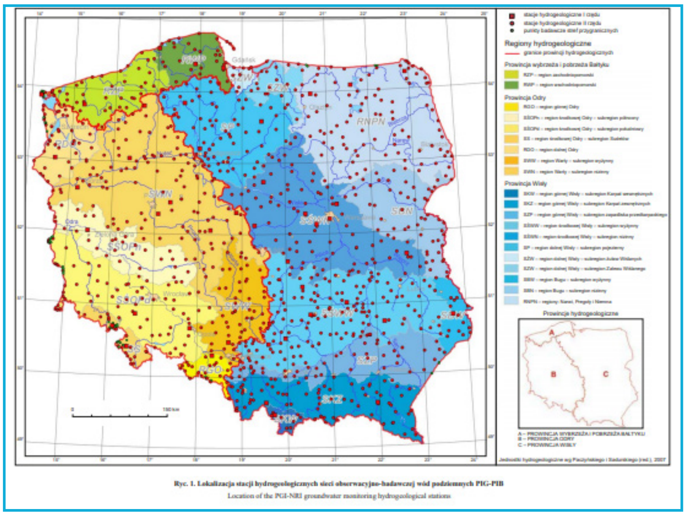


Fig. 131 - Groundwater monitoring Network in Poland. Source: Polish Geological Institute – National Research Institute (PIG-PIB)

PROCESSING AND DISSEMINATION

Groundwater Monitoring database (MWP database) includes:

- Information on monitoring points;
- Groundwater level and spring discharge measurements (since 1974); and
- Groundwater chemical composition analysis (since 1991).

The monitoring data and the outcomes of analysis are published on-line in Quarterly Groundwater Information Bulletin and Hydrogeological Yearbook.

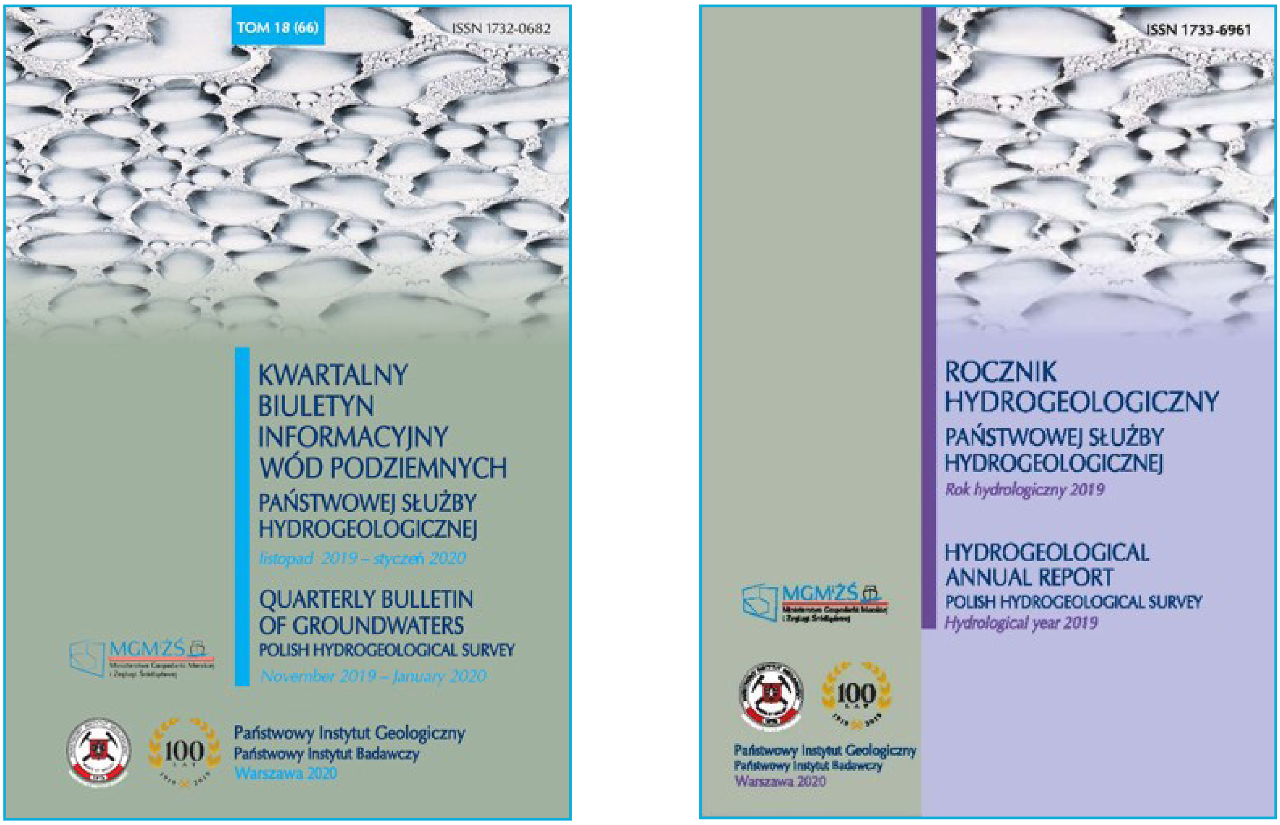


Fig. 132 - Quarterly Bulletin of groundwaters and Hydrogeological Annual

Sources

- **Feedback from the Polish Geological Institute - National Research Institute (PIG-PIB)** - received on 05-10-2020;
- **National Water Management of Poland** - https://www.kzgw.gov.pl/index.php/en/about-kzgw/president-s-duties;
- **Polish Geological Institute – National Research Institute, Groundwater Monitoring (1)** - https://www.pgi.gov.pl/en/phs/tasks/9031-groundwater-monitoring1.html;
- **Polish Geological Institute – National Research Institute, Groundwater Monitoring (2)** - https://www.pgi.gov.pl/gdansk/wody-podziemne-pomorza/monitoring-wod-podziemnych/6389-monitoring-wod-podziemnych.html; and
- **Polish Geological Institute – National Research Institute, Groundwater Monitoring and research network. Transboundary monitoring networks in 2012** - https://www.pgi.gov.pl/en/phs/tasks/9006-groundwater-monitoring-and-research-network.html.

Portugal

Capital city: Lisbon
Inhabitants: 10.3 Million

INSTITUTIONAL SETTING AND PURPOSE

The Portuguese Environmental Agency (APA) is in charge of the National Groundwater Monitoring Network of Portugal.

The monitoring policy of APA includes not only the measurement networks but also measuring instruments, collection and validation procedures, the database system for data storage, and simulation models to support water management and planning.

CHARACTERISTICS OF THE NETWORK

The National Water Resources Information System (SNIRH) contains 22,639 groundwater registered points, 7,864 of them have detailed information. At a national level, 592 points belong to the 'quantity network' and 780 to the 'quality network'.

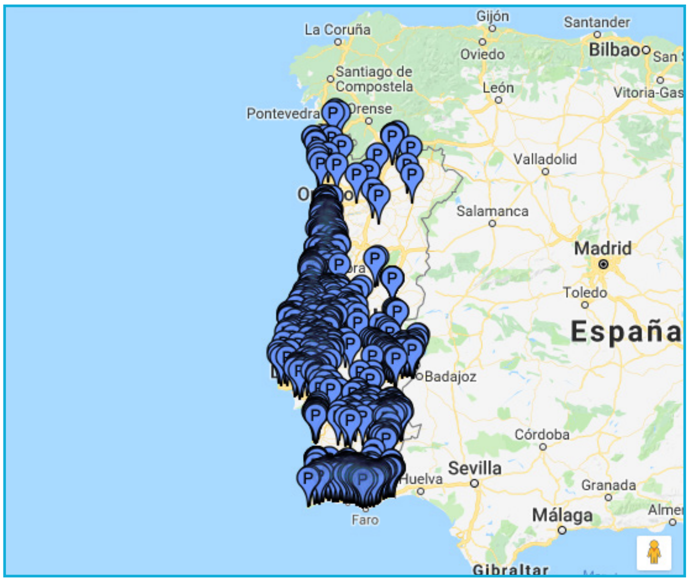


Fig. 133 - Groundwater Monitoring Network of Portugal. Source: SNIRH

PROCESSING AND DISSEMINATION

The monitoring stations can be visualized in an interactive portal maintained by the SNIRH, figure 133.

The groundwater quantity report (Boletim de quantidade) is based on the quantitative groundwater monitoring network and contains an assessment of groundwater level change country-wide. In most of aquifer systems the measurements started in the 70's, and the frequency of observations is monthly. In last several years, some piezometers have been equipped with sensors and the data are monitored daily. The groundwater quantity report plays an important role, especially during drought periods to alert for the decreasing of groundwater level.

The average groundwater level and the 20%-percentile are determined for every month for each well from the beginning of the measurements until the end of the previous hydrological year. A new station is included in the calculations only after 3 years of recording data. For the current hydrological year, the value from the analysed month is compared with the previous statistics and divided in three classes: above average, between the average and the 20% percentile, and below the 20% percentile. Values below the 20% percentile are considered as "very low". At the end, a groundwater body is classified according to the class with highest frequency.

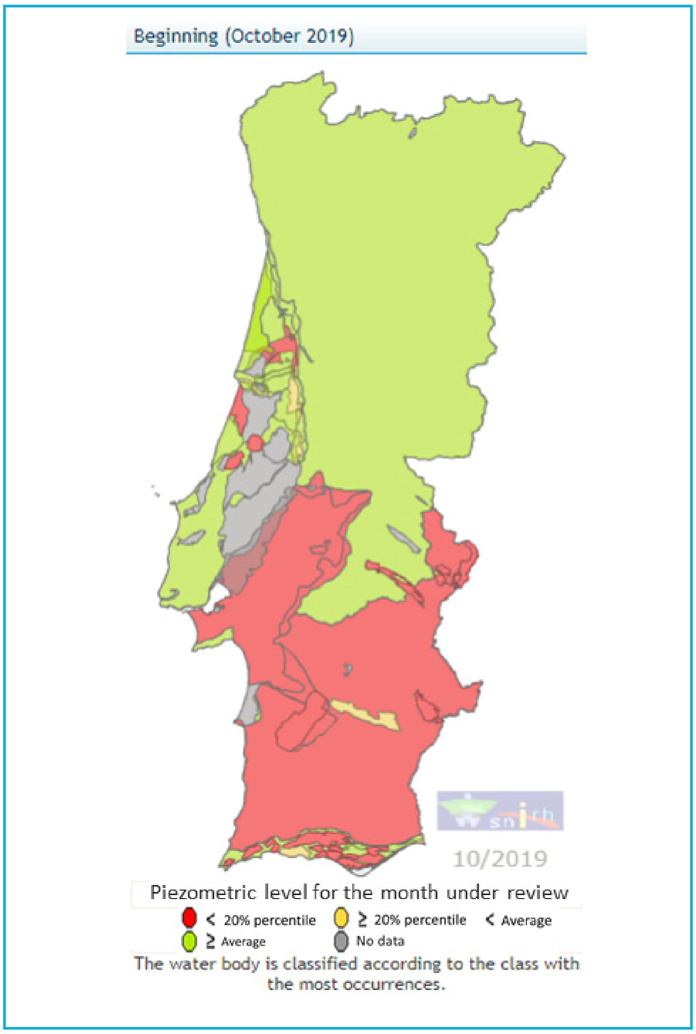


Fig. 134 - State of groundwater levels in Portugal for October 2019. Source: SNIRH, monthly bulletin

If two classes have an equal number of occurrences, the classification considers the worst scenario according to the precautionary principle. Applying this principle, a map of piezometric levels for Portugal is built. For October 2019, the piezometric levels at 232 points were observed in 44 groundwater bodies, figure 134.

This analysis is done each month for all the individual groundwater bodies, including a graph with the monthly evolution of the hydrological year, figure 135.

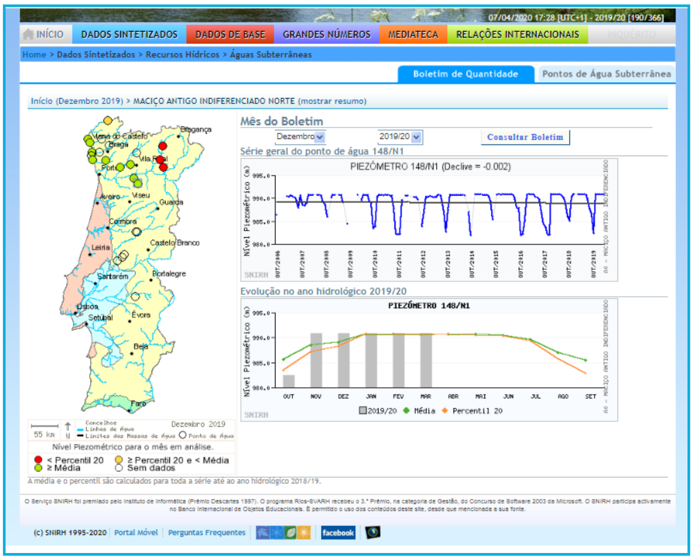


Fig. 135 - Groundwater level analyses for selected monitoring point. Source: SNIRH, monthly bulletin

Sources

- **National Water Resources Information System (SNIRH), National Groundwater Monitoring Network** - https://snirh.apambiente.pt/index.php?idMain=1&idItem=1.4;
- **SNIRH, National Groundwater Monitoring Network. Framework** - https://snirh.apambiente.pt/index.php?idMain=1&idItem=1.4&idSubItem=BOL; and
- **SNIRH, National Groundwater Monitoring Network, Monthly bulletin** - https://snirh.apambiente.pt/index.php?idMain=1&idItem=1.4&idSubItem=BOL&massaagua=2039044.

Russian Federation

Capital city: Moscow
Inhabitants: 144.5 Million

INSTITUTIONAL SETTING AND PURPOSE

The Ministry of Natural Resources and Environment (Minprirody) is in charge of policy making and regulation in the field of research, usage and conservation of natural resources. This includes the subsoil, water bodies, forest, fauna, hydrometeorology, wastewater, environmental monitoring and pollution control. Minprirody supervises the Federal Service for Hydrometeorology and Environmental Monitoring, and the Federal Agency for Water. National environmental monitoring includes groundwater monitoring as subsoil sub-monitoring program. At the same time groundwater is the part of water resources sub-monitoring program. The main purpose of the national groundwater monitoring program is to assess the status of groundwater resources and make forecasts; this includes an estimation of operational groundwater reserves and their current use. National network is composed of regional and local monitoring networks, the example of St. Petersburg's network is described below.

CHARACTERISTICS OF THE NETWORK

The Committee for Nature Use, Environmental Protection and Ecological safety established groundwater monitoring system in 2005 in St. Petersburg. By the end of 2018, the network was operated by 61 observation points, figure 136. Among them 49 wells are drilled in the shallow aquifer , 5 wells are in the Upper Intermoraine-, 1 well is in the Lower Intermoraine-, and 5 wells are in the Vendian Aquifer. 44 monitoring wells are equipped with automatic measuring instruments.

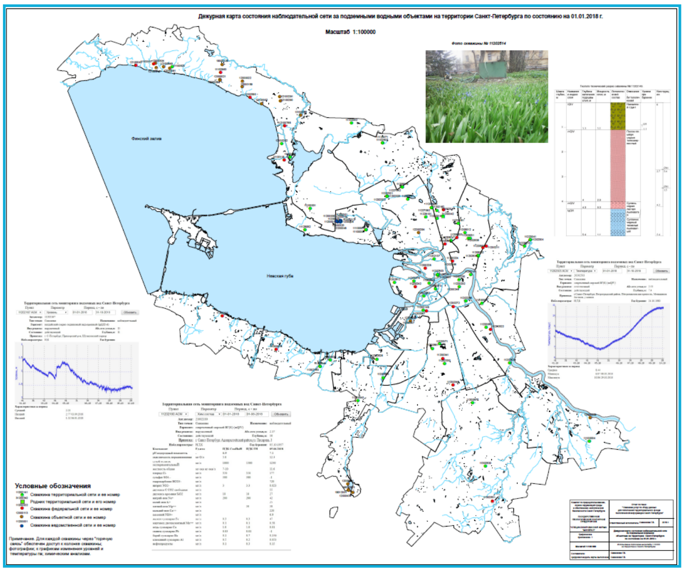


Fig. 136 - Map of groundwater monitoring network status in St. Petersburg as of January 1, 2018

PROCESSING AND DISSEMINATION

The Centre for National Monitoring of subsoil and regional works "Hydrospetzgeologiya" under the Federative Agency on subsoil publishes reports on state and seasonal forecasting of groundwater levels. See figure on next page.

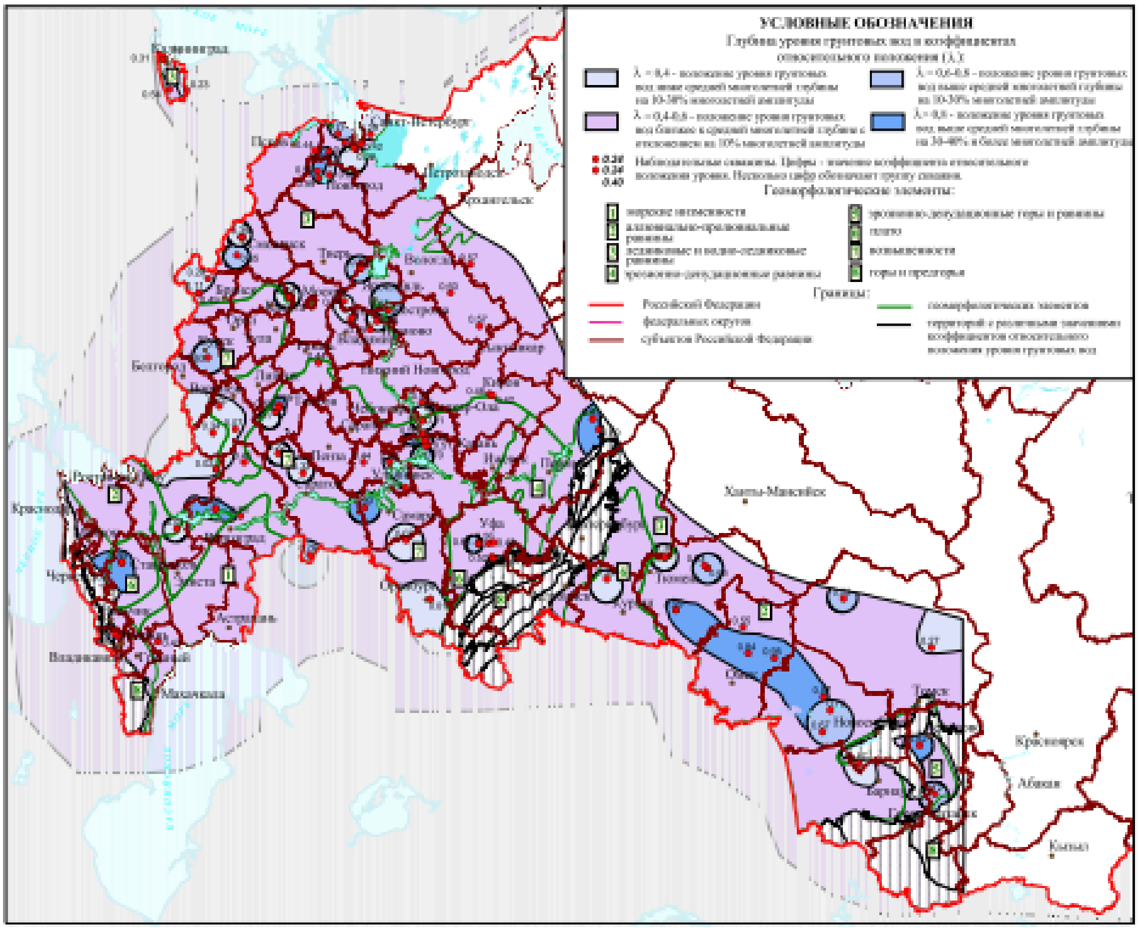


Fig. 137 - The prognoses of maximal groundwater levels in the European part of Russia and the West Siberia (2020)

Sources

- **AQUASTAT. Country Profile - Russian Federation** - http://www.fao.org/nr/water/aquastat/countries_regions/RUS;
- **Ecological Portal of St. Petersburg. Groundwater Observation System** - http://www.infoeco.ru/index.php?id=243;
- **Information site on the state of the subsoil of the Russian Federation. Forecasts and reports** - http://www.geomonitoring.ru/inform_product_svodki.html;
- **Information site on the state of the subsoil of the Russian Federation. Newsletter on the status of subsoil in the Russian Federation** - http://www.geomonitoring.ru/inform_product_ib.html; and
- **Subsystem of monitoring of the state of the subsoil. Directions of work of the Ministry of Natural Resources of Russia** - http://mnr.gov.ru/activity/directions/gosudarstvennyy_ekologicheskiy_monitoring/podsistema_gosudarstvennogo_monitoringa_sostoyaniya_nedr.

Serbia

Capital city: Belgrade
Inhabitants: 6.9 Million

INSTITUTIONAL SETTING AND PURPOSE

The Republic Hydrometeorological Service of Serbia (RHMZ) is the organization in charge of the groundwater monitoring in Serbia.

The RHMS develops the national groundwater monitoring network, maintains wells installation, collects, records, controls and archives observed and measured data from the network and conducts analysis.

CHARACTERISTICS OF THE NETWORK

In 2015, it was reported that in Serbia there are 409 piezometers for groundwater table observation and 34 for groundwater quality observation. These piezometers are distributed in a total of 34 groundwater bodies in the country. Groundwater observation points are classified as: the main, the first order and the second order. The main stations are representative for larger areas.

Groundwater levels are measured daily and groundwater quality once per year. First order stations are placed in profiles perpendicular to the river flow, hence approximately along the line of the groundwater level. Measurements of the level and temperature are taken six times per month. Second order stations are addition to the first order, being as a network of squares and triangles between the profiles. Measurements of the level and temperature are taken three times per month.

PROCESSING AND DISSEMINATION

RHMS provides the data on groundwater level fluctuations as a graph with 10 last measured values, figure 138. Additionally, an interactive groundwater station network map is available, with links to lithological profiles, general data on stations, statistical analysis of groundwater levels, figure next page.

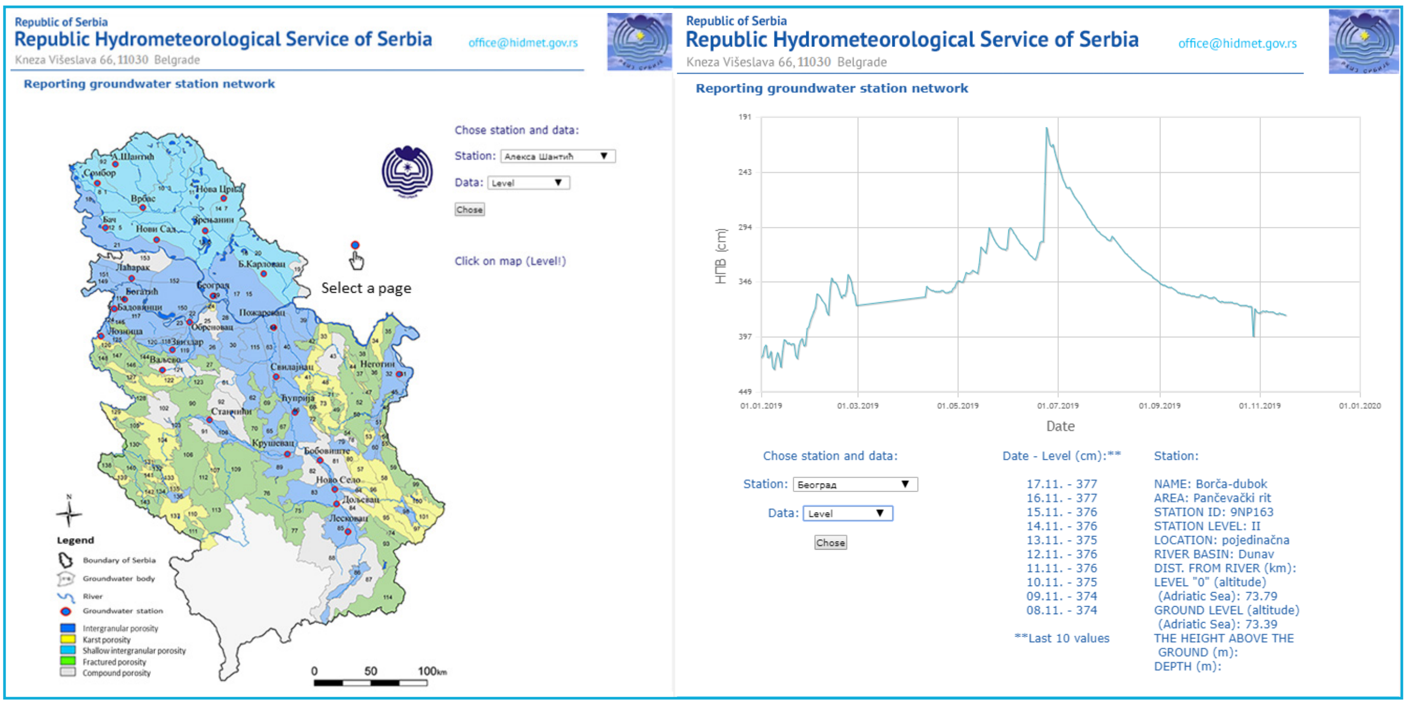


Fig. 138 - Groundwater monitoring network in Serbia (left) and groundwater level fluctuation graph of Belgrade station (right). Source: RHMZ

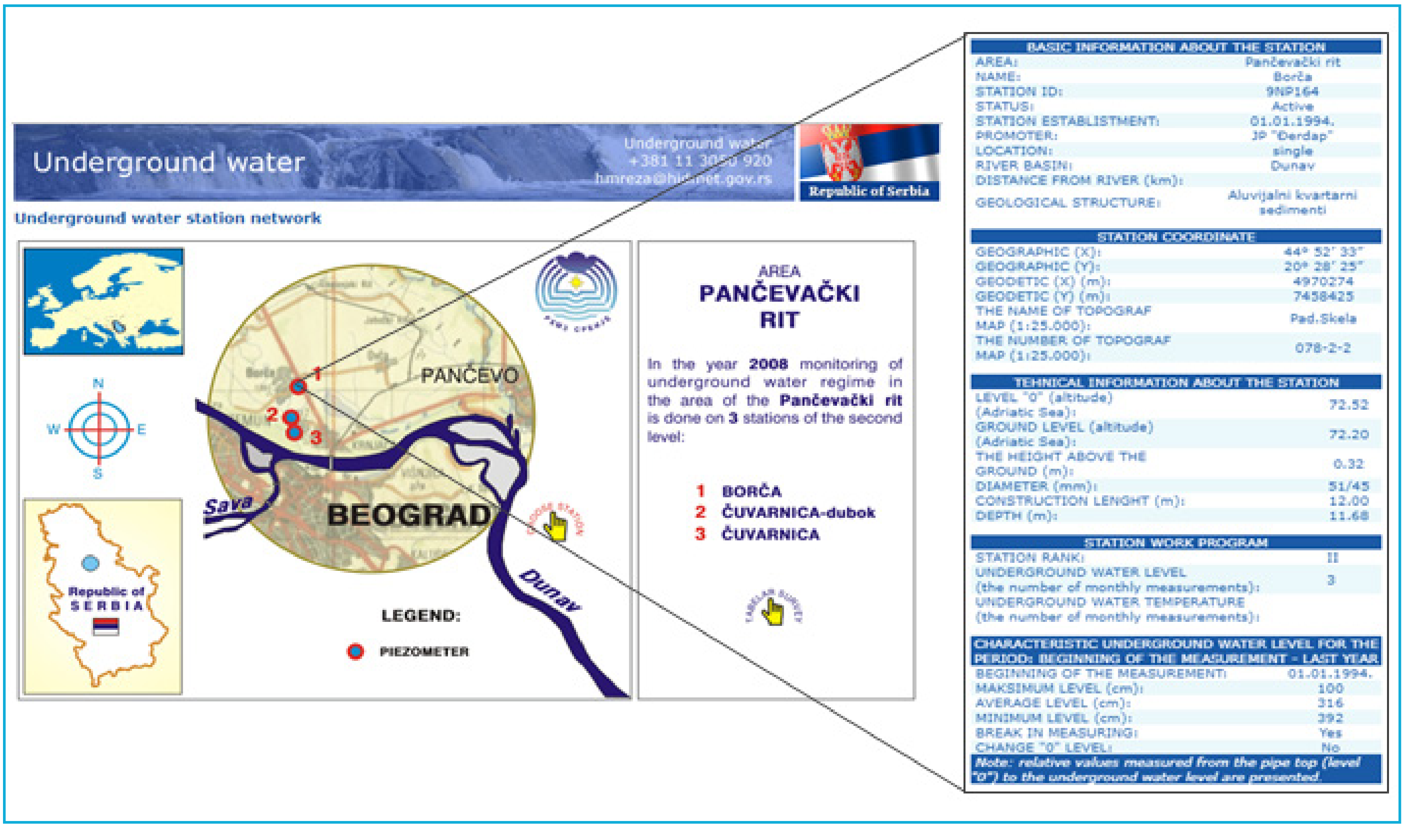


Fig. 139 - Interactive station network map with observation points in Belgrade. Source: RHMZ

Sources

- **Republic Hydrometeorological Service of Serbia. Groundwater** - http://www.hidmet.gov.rs/eng/hidrologija/podzemne/o_odseku.php;
- **Republic Hydrometeorological Service of Serbia. Groundwater monitoring networks** - http://www.hidmet.gov.rs/eng/hidrologija/podzemne/9np.php; and
- **Republic Hydrometeorological Service of Serbia. Groundwater stations and profiles** - http://www.hidmet.gov.rs/eng/hidrologija/podzemne/naslovna.php.

Spain

Capital city: Madrid
Inhabitants: 46.9 Million

INSTITUTIONAL SETTING AND PURPOSE

The Ministry for Ecological Transition and Demographic Challenge is in charge of groundwater monitoring in Spain. The Ministry executes the Governmental policy on energy and the environment for the transition to a more ecological and social productive model. The objective of the monitoring network was adapted in accordance to the EU Water Framework Directive when hundreds of new piezometers were introduced in every basin for determining chemical status of water bodies.

CHARACTERISTICS OF THE NETWORK

This network includes wells with one or two filters, and artesian wells. The data are measured once a month. In total, there are more than 2,700 piezometers included in the network.

PROCESSING AND DISSEMINATION

The Monitoring Network Information System from the Ministry of Agriculture and Fisheries, Food and Environment and the Ministry for Ecological Transition offers information about the hydrological monitoring in Spain, including the groundwater monitoring network. Since 2011, the management of the network is done by the General Water Authority (DGA).

By selecting a well, metadata (coordinates, elevation well depth and others) and time-series (all historical monthly data) are visualised in the system. This information can also be downloaded (in PDF or Excel files).

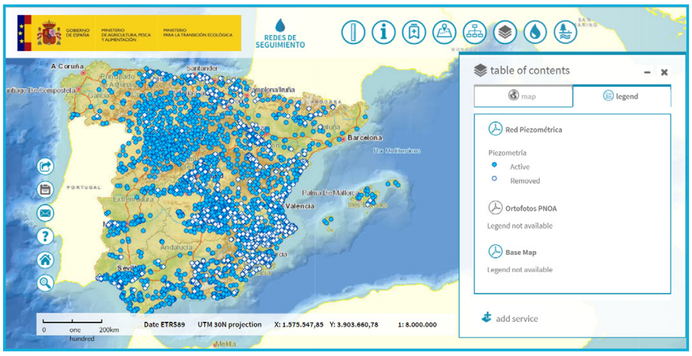


Fig. 140 - Groundwater monitoring network of Spain. Source: The Monitoring Network Information System

Sources

- **Control network for the quantitative status of groundwater** - https://www.miteco.gob.es/va/cartografia-y-sig/ide/descargas/agua/red-piezometrica.aspx;
- **Information System of Monitoring Networks and Hydrological Information from MITECO** - http://sig.mapama.es/redes-seguimiento; and
- **Ministry for Ecological Transition and Demographic Challenge (MITECO). Piezometry and volume of groundwater** - https://www.miteco.gob.es/es/estadistica/temas/estadisticas-ambientales/pto3_4_sintesis03_tcm30-123726.pdf.

Sweden

Capital city: Stockholm
Inhabitants: 10.2 Million

INSTITUTIONAL SETTING AND PURPOSE

The Geological Survey of Sweden (SGU) has been commissioned by the Swedish Ministry of Enterprise and Innovation to carry out and manage national monitoring of groundwater.

The network aims to study temporal variation in quantity and composition of groundwater, in relation to geology, topography and climate, for reference purposes, forecasts, environmental control and resource estimations.

CHARACTERISTICS OF THE NETWORK

The groundwater network consists of 600 monitoring stations in some 200 areas (figure 141). Of these, about half date back to c. 1970, whereas the other half was established quite recently (2018-2020). As of today, the monitored levels are recorded automatically, 4-6 times per day, and transmitted to an online database. The historic part of the data set (c. 1970 to 2018) was measured manually at a typical frequency of twice a month.

The Swedish groundwater resources are mainly found in quaternary deposits on top of fractured crystalline bedrock; to reflect the different roles in drinking-water supply, as well as, differences in the dynamics of groundwater-level fluctuation, the resources are divided into two conceptual entities. Glaciofluvial eskers form the major resources, with potential to serve as supplies for municipal water works. In contrast, minor resources are abundant and widespread, but typically limited to supply private wells (drilled boreholes). Although the concept of a minor resource includes several hydrogeological settings, the most typical setting is a thin layer of glacial till (a few meters) on top of sparsely fractured crystalline bedrock.

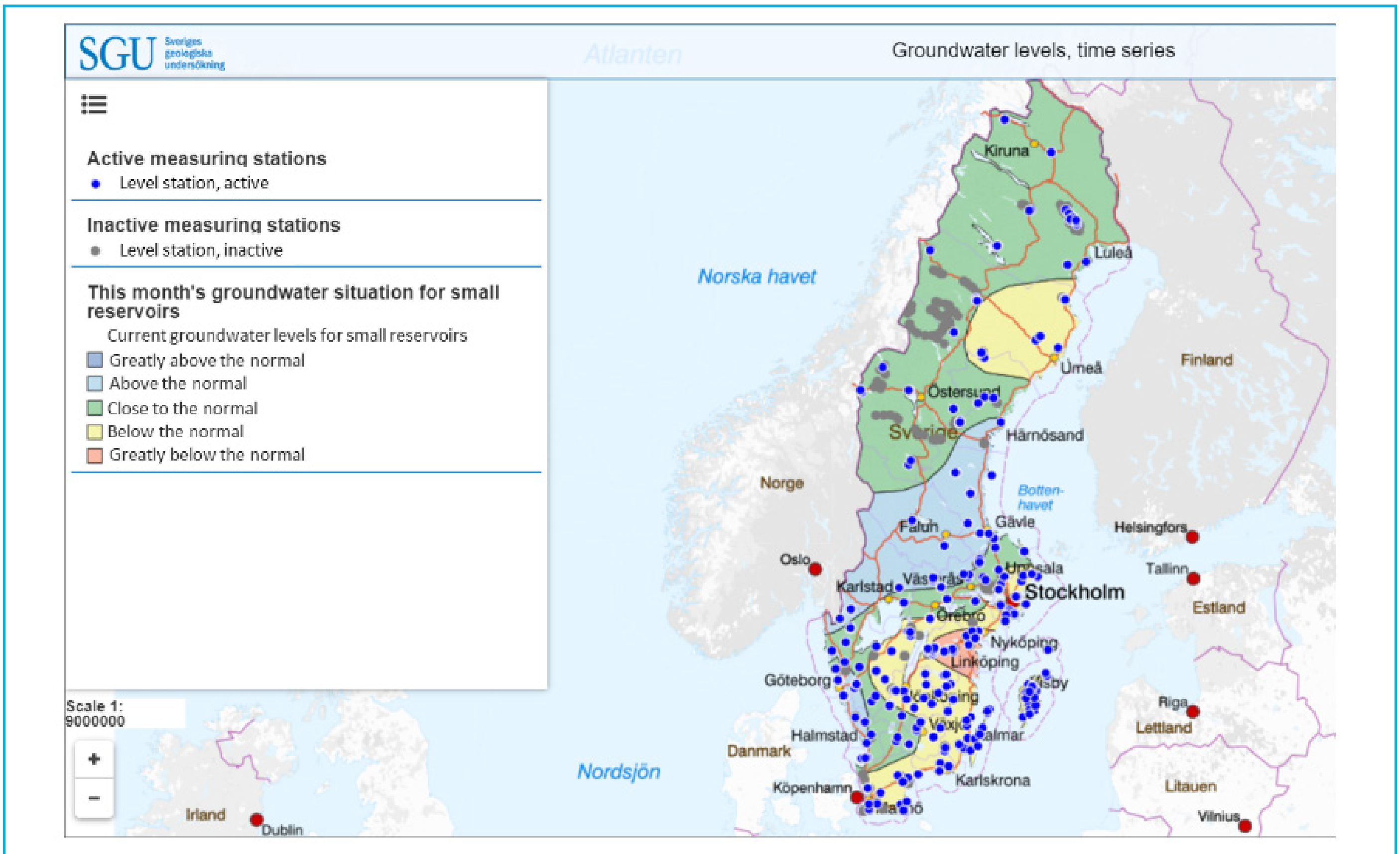


Fig. 141 - Groundwater monitoring network in Sweden. Source: SGU

PROCESSING AND DISSEMINATION

Groundwater data are used to set up a semi-distributed, process-based catchment model (HYPE; Hydrological Predictions for the Environment, developed by SMHI; the Swedish Meteorological and Hydrological Institute). The model is operated at the national scale to provide weekly reports of the prevailing groundwater situation (calculated groundwater level in context of its normal seasonal variation; figure 142). Moreover, the model estimates a range for the expected change in groundwater situation within the next 1 to 6 months, which is based on weather forecasts combined with climatological data.

Measured and simulated groundwater-level time-series are available for all monitoring stations (black line in figure 143) and presented in context of reference statistics (coloured fields in figure 143). The reference statistics is based on long-term monitoring (ranging from 10 to 50 years) and used to interpret groundwater levels in perspective of the past, either with respect to seasonal patterns (figure 143a) or, more simply, just in terms of historic variability.

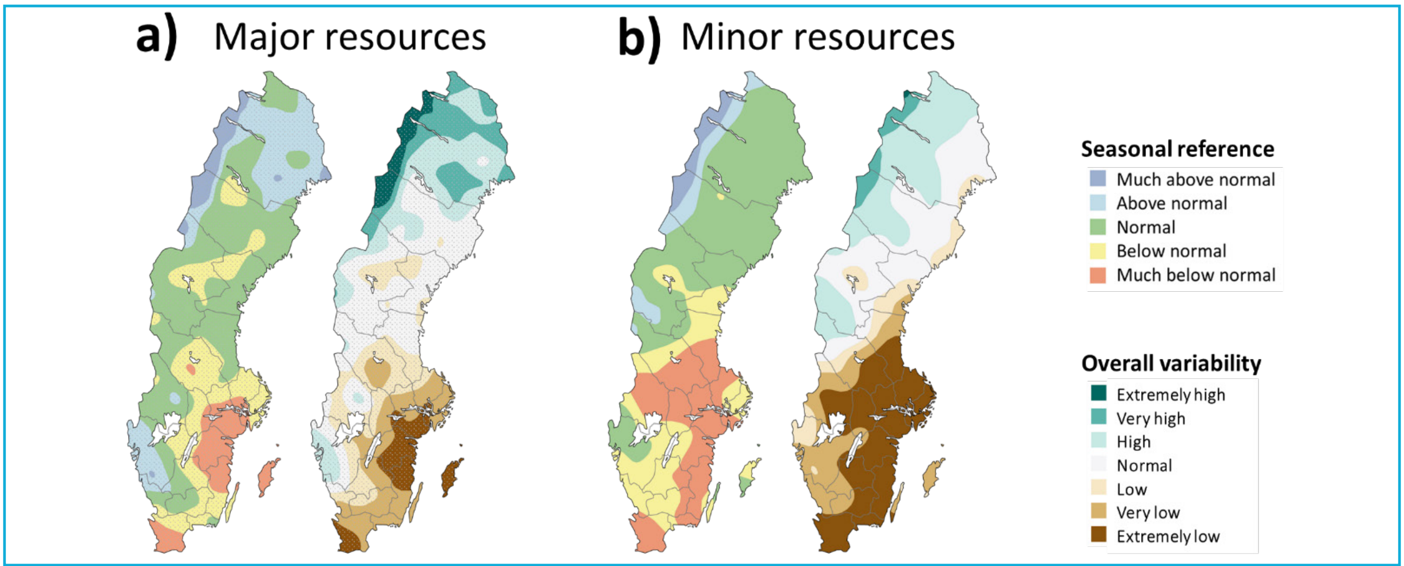


Fig. 142 - Groundwater situation in Sweden, October 2020, in: a) major resources (i.e., glacifluvial eskers) and b) minor resources (e.g., thin glacial till on top of fractured crystalline bedrock). Two statistical references are employed: groundwater situation in context of seasonal variation and in terms of overall variability. Source: SGU

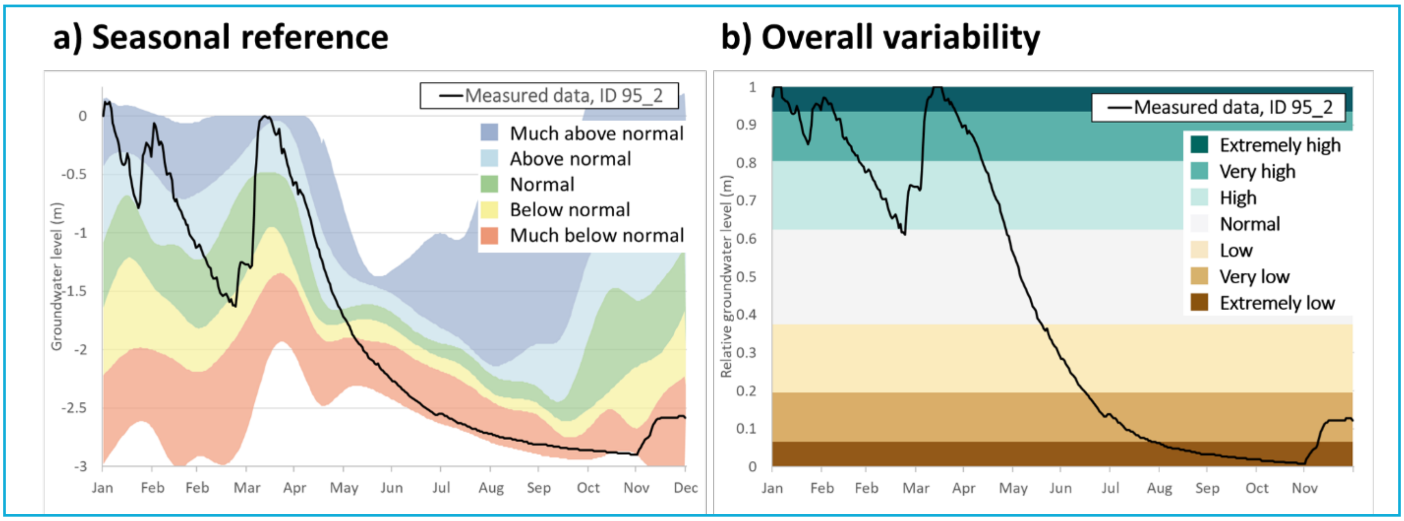


Fig. 143 - Groundwater time-series (2018) for monitoring station 95_2; in context of a) seasonal variation and b) in terms of overall variability. Source: SGU

Sources

- **Feedback from SGU** - received on 13-10-2020;
- **SGU. General information on the SGU monitoring program and concepts used** - https://apps.sgu.se/grundvattennivaer/;
- **SGU. Current groundwater levels** - https://apps.sgu.se/grundvattennivaer/aktuella-grundvattennivaer.html;
- **SGU. Groundwater levels (map application)** - https://apps.sgu.se/kartvisare/kartvisare-grundvattenniva.html; and
- **SGU. Environmental monitoring of groundwater** - https://www.sgu.se/grundvatten/miljoovervakning-av-grundvatten/.

Switzerland

Capital city: Bern
Inhabitants: 8.6 Million

INSTITUTIONAL SETTING AND PURPOSE

More than 80% of Switzerland's drinking water derives from groundwater. The Federal Act on the Protection of Waters (Art. 57) requires the Swiss Confederation to carry out surveys of hydrological conditions with relevance to Switzerland as a whole. The National Groundwater Monitoring (NAQUA) programme is responsible for the monitoring of quality and quantity of groundwater resources nationwide. NAQUA is conducted by the Federal Office for the Environment (FOEN), in close collaboration with the cantonal authorities.

The purpose of NAQUA is manifold:

- to document the status and the trends in groundwater quantity and quality on a national level;
- identify the occurrence of problematic substances at an early stage and to systematically follow up any undesirable developments;
- check the effectiveness of protective measures already adopted (e.g. ecological measures in agriculture) and identify the need for further measures; and
- to characterise and classify the most important groundwater resources in Switzerland.

CHARACTERISTICS OF THE NETWORK

In total, 545 sites are available for groundwater quality monitoring and 91 sites for groundwater quantity monitoring. The quantity of groundwater is measured in springs, piezometers and extraction wells of the NAQUA programme's QUANT module (quantity monitoring). Half of the sites are operated by the federal administration and half by the cantons or water supply companies. Most monitoring sites are equipped for remote data transmission. Only few cantonal monitoring sites upload the data regularly, hence monitored data are only available with delay. 30 monitoring sites of the QUANT module are also part of the TREND module and 17 are part of the SPEZ module, both modules monitor groundwater quality.

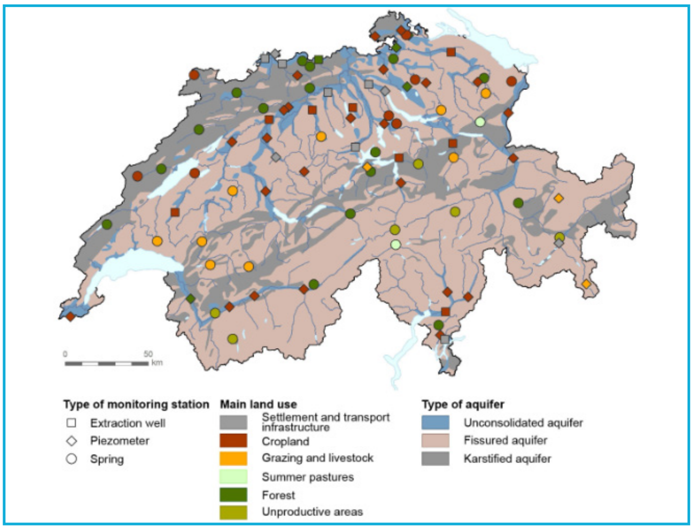
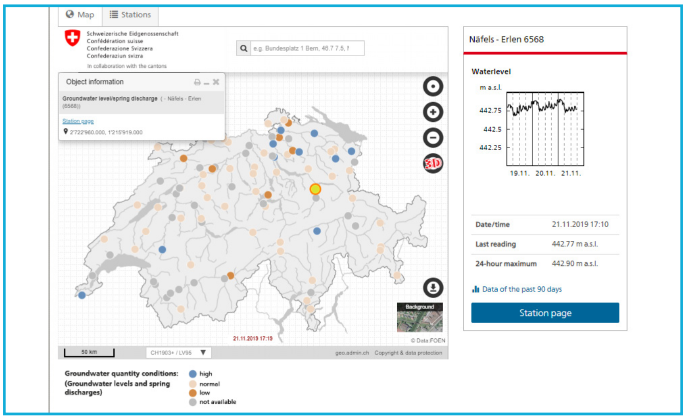


Fig. 144 - QUANT module sites for monitoring groundwater quantity (2019 status). Source: NAQUA National Groundwater Monitoring

PROCESSING AND DISSEMINATION



The platform "hydrodaten.admin.ch" gives an overview of the current groundwater situation in Switzerland in stations that are equipped with remote data transmission, figure 145. Changes of the current groundwater levels and spring discharges are presented on a map and in a hydrograph; the values are compared with the expected conditions. The data are shown as below, above or equal to the long-term average for each month. The calculation is based on percentiles of the dataset for the full monitoring period (basic data in masl and l/min or m3/s). Lower

Fig. 145 - Groundwater situation map as of 21.11.2019. Source: NAQUA National Groundwater Monitoring

groundwater level or spring discharge than the average conditions are reached if the current value is below the long-term 10% percentile, for example it is among the lowest 10% of all the data ever measured for the relevant month. A groundwater level or spring discharge between the 10% and 90% percentiles means that conditions are normal. If the current value is above the 90% percentile, a higher than the long-term average condition is reached, figure 146.

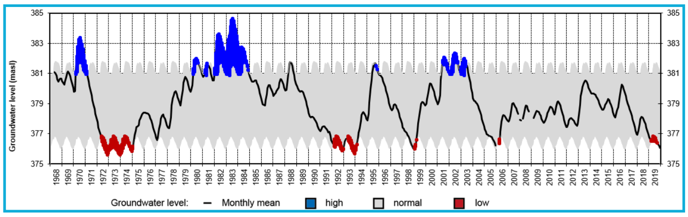


Fig. 146 - Monitoring site with high, normal, and low groundwater level

The collected data from NAQUA are used in national and international reporting. Historical data for the individual monitoring sites can also be accessed on "hydrodaten.admin.ch". The relevant datasheets contain the daily averages for each year and the long-term mean groundwater levels and spring discharges. A Groundwater Bulletin is also available on the website of FOEN in French and German. It provides textual information on the state and changes of groundwater levels and spring discharge, figure 147.

The indicator "Groundwater levels and spring discharge rates" provides a national overview of the frequency of low, normal and high groundwater conditions year on year, figure 148.

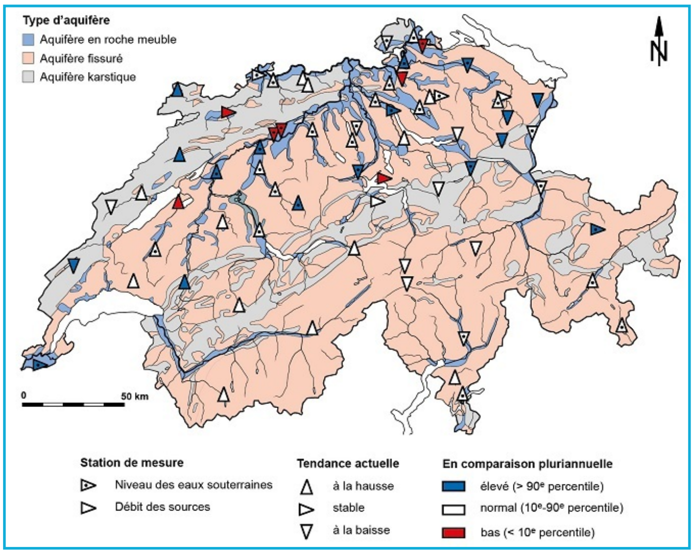


Fig. 147 - Groundwater levels and spring discharge (status as of November 5, 2019) current trend and multi-year comparison. Source: NAQUA National Groundwater Monitoring

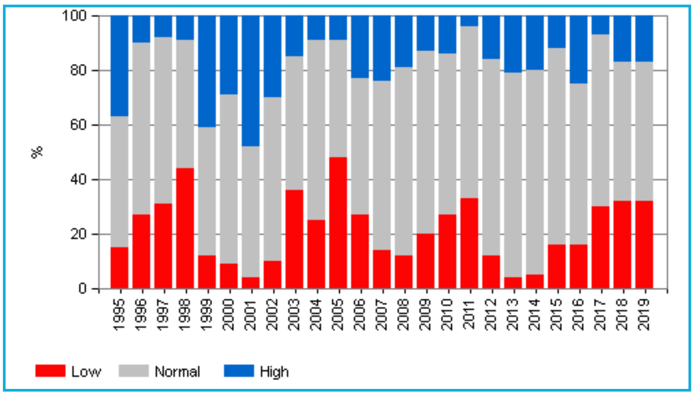


Fig. 148 - Indicator Groundwater levels and spring discharge rates. Percentage of monitoring stations at which low, normal and high groundwater levels or spring discharge rates were recorded in each year. Source: NAQUA National Groundwater Monitoring

Sources

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- **FOEN. Groundwater bulletin (available in German and French)** - https://www.hydrodaten.admin.ch/en/groundwater-bulletin.html;
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- **FOEN. QUANT module** - https://www.bafu.admin.ch/bafu/en/home/topics/water/info-specialists/state-of-waterbodies/state-of-groundwater/naqua-national-groundwater-monitoring/quant-module.html; and
- **FOEN. Indicator groundwater levels and spring discharge rates** - https://www.bafu.admin.ch/bafu/en/home/themen/thema-wasser/wasser--daten--indikatoren-und-karten/wasser--indikatoren/indikator-wasser.pt.html/aHR0cHM6Ly93d3cuaW5kaWthdG9yZW4uYWRtaW4uY2gvUHVibG/ljL0FlbURldGFpbD9pbmQ9V1MwNTYmbG5nPWVuJlN1Ymo9Tg%3d%3d.html.

United Kingdom

Capital city: London
Inhabitants: 66.7 Million

INSTITUTIONAL SETTING AND PURPOSE

The regulatory environment agencies are responsible for managing and protecting groundwater in the UK. As the UK comprises for devolved nations, each has an agency: Environment Agency (England), Scottish Environment Protection Agency (SEPA), Natural Resourced Wales (NRW) and Northern Ireland Environment Agency (NIEA).

Groundwater monitoring is one of the statutory activities carried out by the agencies to comply with the EU Water Framework Directive (WFD), EU Groundwater Directive (GD) and EU Nitrates Directive (ND) and UK legislation relating to water resource management and protection, e.g. status and trend assessment for the WFD and GD, nitrate vulnerable zone delineation (ND) and abstraction licencing .

In particular, the British Geological Survey (BGS) has a role to collate data for a sub-set of sites that are part of the environment agencies water level monitoring network. These data are used as is described in the following sections, for instance, to produce the Hydrological Summary (see below).

CHARACTERISTICS OF THE NETWORK

The groundwater monitoring network is comprised by 181 sites, from which 166 are in England, 3 in Northern Ireland and 1 in Scotland, figure 149. Data from 28 stations chosen as index wells are compiled every month to provide continually updated regional trends and variations in groundwater resources, in the Hydrological Summary for the UK.

Groundwater levels are measured manually using a dipper, or automatically using a pressure transducer. Automatic readings are either stored in a data logger (the site is visited periodically to retrieve the measurements) or sent automatically over the phone network to a database through telemetry.

It is important to notice that the monitoring networks operated by the national agencies comprise many more monitoring sites than are used for the Hydrological Summary. For instance, there are around 3500 groundwater quality (chemical) monitoring sites, possibly double this number for groundwater level.

Fig. 149 - Groundwater situation map as of 21.11.2019. Source: NAQUA National Groundwater Monitoring

PROCESSING AND DISSEMINATION

This section focuses only in the processing and dissemination of data by BGS, although is it noteworthy that each national agency process and disseminate data and information from their own managed groundwater monitoring networks as well.

BGS hosts the National Groundwater Level Archive. It is the national repository for groundwater level data, and it also collects groundwater level data from their research projects.

The WellMaster database is another data storage (in addition to the National Groundwater Level Archive), where currently water level data from 60,000 boreholes are available. These data come from logs of boreholes drilled for water supply, and most of them are a single historical reading of the water level after drilling or when the borehole was surveyed.

The Hydrological Summary is produced monthly by the National Hydrological Monitoring Programme. The Programme is a collaboration between the Centre for Ecology and Hydrology (CEH) and the British Geological Survey (BGS). The Hydrological Summary includes information from rainfall, river flows, reservoirs and groundwater.

The data used for the Hydrological Summary are a small sub-set of the Environment Agency's monitoring network. The sub-set is the collection of data that is operated for water resource management purposes including EU Water Framework Directive status assessment and River Basin Management Plans (RBMP) reporting. Of the index boreholes on the BGS map, some of these are telemetered (all Environment Agency boreholes) and the data can be obtained directly by API, while others are dipped manually.

Normalisation methods are applied to display data in the Hydrological Summary. A spot map is created based on the end of month levels, figure 151.

For a given month, all measurements of that month in the period of record of each borehole are ranked. The map displays the rank of the current month with respect to all historical measurements of that month, figure 151. Then, the point is coloured according to the rank's ratio (total number of month/rank of current months), in seven possible categories, table below.

Category	Ratio
Exceptionally high levels	0.950000 – 1.100000
Notably high levels	0.870000 – 0.949999
Above normal	0.720000 – 0.869999
Normal range	0.280002 – 0.719999
Below normal	0.130002 – 0.280001
Notably low levels	0.050002 – 0.130001
Exceptionally low levels	0.000000 – 0.050001

Fig. 150 - Categories applied to ratio of the rank

When a new high or low level is established for a given month/period, the spot is circled with arrows.

ArcMap documents and output image/PDF files are produced from spreadsheet files containing level ranking and ratios using a Python script.

Groundwater monitoring stations are used in the analysis only if they have high hydrometric data quality and long records of at least 30 years. The data collected for monitoring is used for modelling. Their objective is to simulate fluctuations in ground-

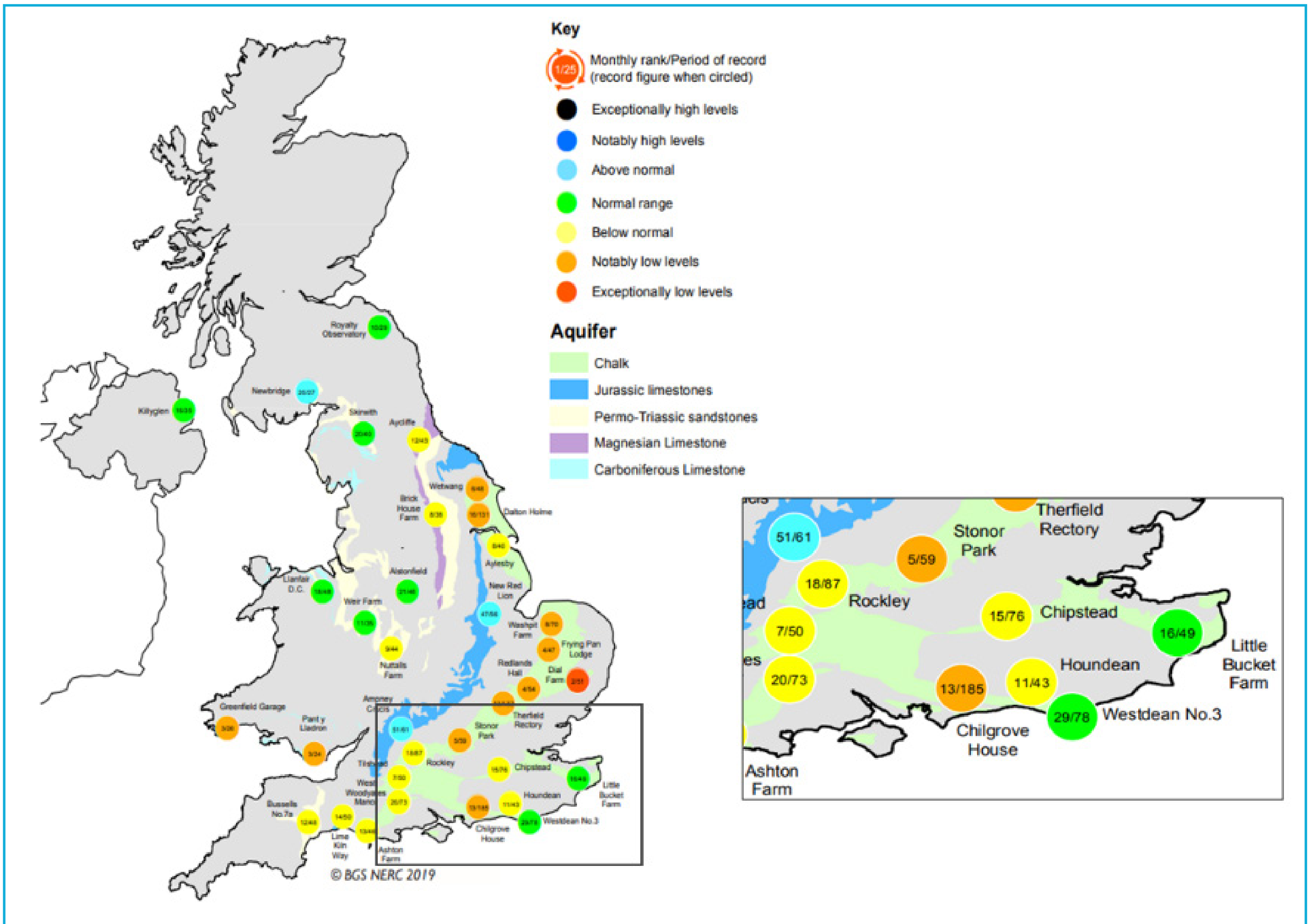

Fig. 151 - Spot map for Groundwater levels July 2019 in the UK (left) and zoomed view with boreholes ranking (right). Source: BGS 2019

water level at 25 sites across the UK to forecast groundwater levels. Each of these models is driven by rainfall and evaporation time-series and has been calibrated against past observations of groundwater level. To forecast the change in groundwater level at a site over the coming one and three months, BGS uses 1 and 3-month ahead climate forecasts produced by a Met Office climate probabilistic model. Each of these two climate forecasts consists of an ensemble of up to 42 members and each member provides a projection of rainfall and temperature into the future. Each member of the two climate forecast ensembles is run through each groundwater model. Thus, a probabilistic groundwater level forecast is produced for each site.

BGS produces forecasts at sites located in most of the principal aquifers of the UK where groundwater abstraction has significantly modified the observed groundwater level, and a hydrograph have not been modelled yet.

Fig. 152 - Fresh spring water at St Ann's Well, Buxton, by: Tom Parnell

Sources

- **British Geological Survey. Groundwater level information** - https://www.bgs.ac.uk/research/groundwater/datainfo/levels/home.html;
- **British Geological Survey. National Groundwater Level Archive** - https://www.bgs.ac.uk/research/groundwater/datainfo/levels/ngla.html;
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- **UK CEH Water Resources Portal** - https://eip.ceh.ac.uk/hydrology/water-resources/;
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ASIA & THE PACIFIC

Afghanistan

Capital city: Kabul
Inhabitants: 38 Million

INSTITUTIONAL SETTING AND PURPOSE

The Hydrogeology Department of the Ministry of Energy and Water (MEW) is responsible for monitoring and managing groundwater in Afghanistan. Additionally, two institutions are involved in groundwater monitoring: The Danish Committee for Aid to Afghan Refugees (DACAAR) and the Afghanistan Geological Survey (AGS), both with different purposes and encompassing different study areas. Since 2003, DACAAR has been conducting groundwater monitoring in 29 provinces of Afghanistan, covering almost 85% of the country's river basins.

The purpose of DACAAR's network is to provide long-term scientific information on groundwater quality and quantity, while the purpose of AGS network is to assess seasonal, areal, and potentially climatic variations in groundwater characteristics in the Kabul Basin, as the most populous region in the country.

CHARACTERISTICS OF THE NETWORK

DACAAR's network consists of 363 monitoring wells that provide information regarding the qualitative and qualitative status of the groundwater resource. This is the only national data source on groundwater in Afghanistan.

The monitoring is made manually through Groundwater Monitoring Teams that visit the wells monthly to measure groundwater levels, electrical conductivity (salinity), pH, temperature and ORP and take water samples for quality analysis on a semi-annual basis. The monitoring wells also have drilled, constructed and modified for long time recording using diver/ data logger. Divers/data loggers are reliable instruments for automatic measurement and registration of the ground water level, salinity and temperature over a long time period. The Divers are installed in tube wells and after a while data are up-loaded to a Diver Mate, then downloaded from the Diver Mate to a PC.

The network from AGS started with 71 wells in the Kabul Basin in 2004, with the assistance of the U.S. Geological Survey. The network was made up exclusively of existing production wells and levels are measured once a month using electric tape water-level meters. Both static and dynamic water levels are recorded. In 2010, AGS established similar groundwater monitoring networks in the cities of Mazar-e-Sharif, Sheberghan and Sar-e Pol.

The figure below shows the distribution of groundwater monitoring wells in Afghanistan.

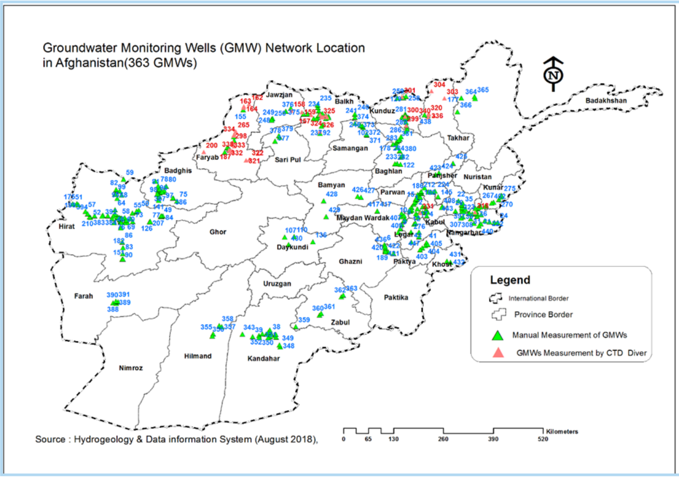

Fig. 153 - Distribution of groundwater monitoring wells in Afghanistan (Source: DACAAR)

And the following figure shows the distribution of groundwater monitoring wells in the Kabul Basin, including wells from the monitoring networks of DACAAR and AGS.

Static groundwater levels in Kabul city were separately collected by the Hydrogeology Department of MEW from 2007 till 2009 and restarted in 2014 up until now. The measurements are gathered from 104 wells monthly throughout the city. Previously, the department focused only on groundwater monitoring of the major cities: Kabul, Nangarhar, Balkh, Herat, and Ghazni. In 2019, the groundwater monitoring system was created in more than 10 cities of Afghanistan where groundwater static levels are being measured monthly.

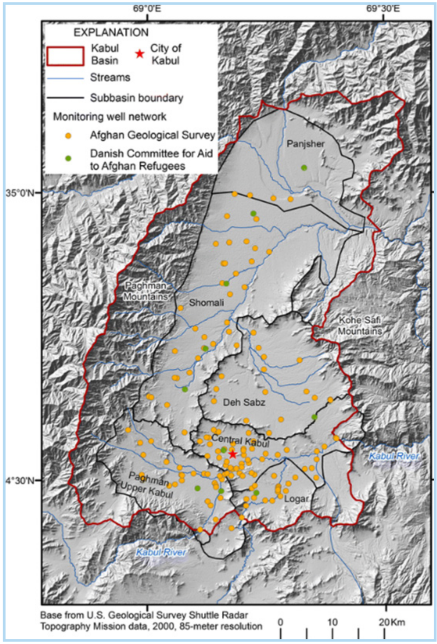

Fig. 154 – Monitoring wells from AGS and DACAAR in the Kabul Basin, Afghanistan

PROCESSING AND DISSEMINATION

DACAAR publishes several times a year various reports on groundwater monitoring, mainly on quality and geophysics. The last report on groundwater levels monitoring is the National Groundwater Monitoring Wells Network Finding Challenges and Recommended Solutions in Afghanistan by M. H. Saffi and A. Jawid, 2013. It reports shortly about the National Groundwater Monitoring Wells Network Database (WSG_SWL) that is developed as a part of DACAAR activities.

The long term quantitative and qualitative GMWs data (2003-2019, see figure on last page) were evaluated, mapped and provided in reports and presentations, and findings were presented in national and international conferences. Reports are available in DACAAR's website .

Since the start of their collaboration, AGS and USGS have released more than 40 reports on the quantity and quality of groundwater and surface water resources. For example, the publication 'Groundwater Levels in the Kabul Basin, Afghanistan, 2004–2013' presents water-level hydrographs for stations in 5 sub-basins. In a different publication, the Seasonal Kendall test is used to determine trends. In general, a relatively little change in the water-level trend during the period of record is observed in the Kabul Basin using Seasonal Kendall test (publication 3), with exception of the Central Kabul sub-basin where groundwater level has decreased from several meters to about 25 m.

The information recorded on the field form and the water-level measurements are maintained in project databases by the AGS.

The collected data on static groundwater levels in Kabul city is processed by the Hydrogeology Department of MEW. Monthly static water level fluctuation reports are prepared and published on Facebook page "Afghanistan Water Resources and Hydrology Services" for the public awareness.

Sources

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- **Danish Committee for Aid to Afghan Refugees (DACAAR) -** https://dacaar.org;
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Australia

Capital city: Canberra
Inhabitants: 25 Million

INSTITUTIONAL SETTING AND PURPOSE

Under the Water Act 2007, the Bureau of Meteorology (BoM) is the institution responsible for delivering water information across Australia to support national decisions. In Australia, groundwater management is vested in the States/Territories. As a consequence, the collection of groundwater data and maintenance of the groundwater monitoring networks is also the responsibility of various organisations including State/Territory water agencies or water authorities. The BoM has been mandated to collate, standardise and disseminate the state collected groundwater information at a national level.

CHARACTERISTICS OF THE NETWORK

In total there are around 910,000 sites with nationally consistent groundwater information across Australia available through the Bureau website. Of these:

- 710,000 have bore log information, including construction, lithology and/or hydrostratigraphy;
- 250,000 have at least one groundwater level measurement, ~2,000 sites are continuously logged with updated groundwater levels released on the Bureau website weekly;
- 200,000 have salinity data; and
- 120,000 have hydrochemistry data.

PROCESSING

Two types of products give an overview of the state of the quantity of groundwater resources in Australia: groundwater level status map and groundwater level trend maps presented as Upper, Middle and Lower aquifer groups (figure 155).

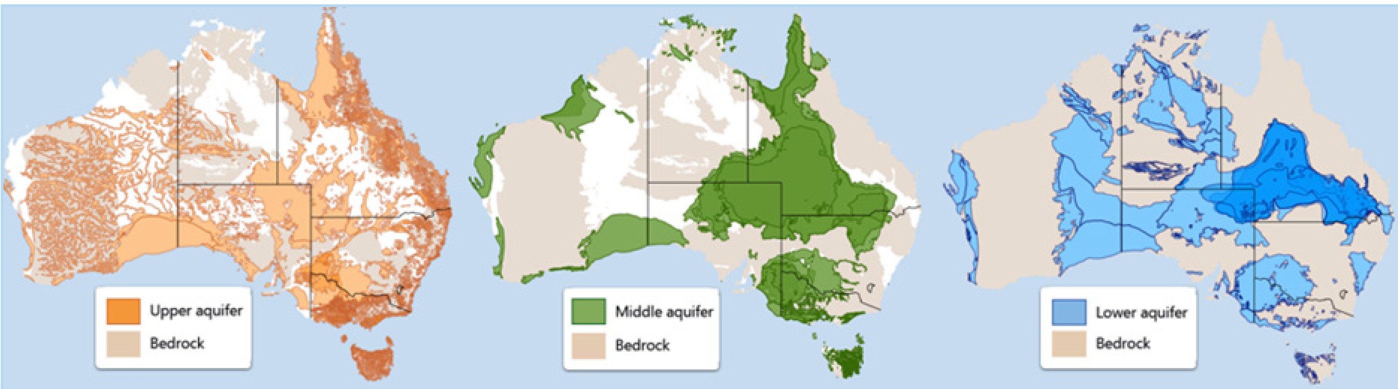

Fig. 155 – Upper, Middle and Lower aquifers across Australia

In order to fully understand these maps, it should be noted that all major aquifers in Australia have been grouped by Upper, Middle and Lower aquifer, according to a methodology based on the Victorian Aquifer Framework (VAF), and further modified to extend across Australia. The objective of this aggregation was to make non-groundwater experts aware of the 3D nature of aquifers. The approach used was first to divide Australia into several "groundwater provinces" (figure 156), and then (using a simplified stratigraphic table) group hydrogeological units into upper, middle and lower aquifer groups. Small and single aquifer systems may not be included in the stratigraphic table given the national perspective of this analysis.

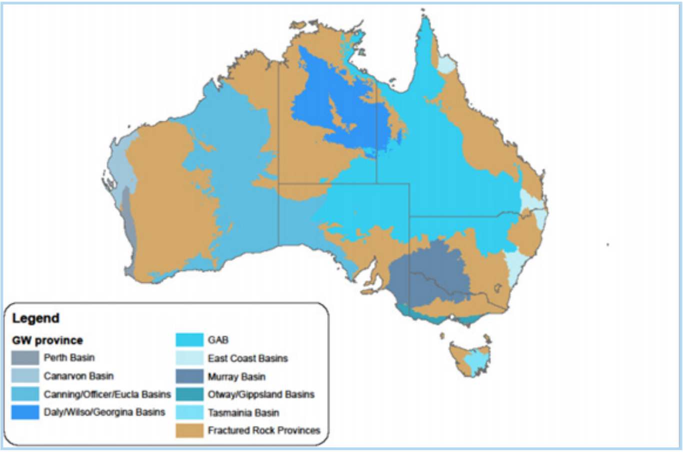

Fig. 156 – Groundwater Provinces across Australia

Groundwater level status maps

Groundwater status maps compare recent groundwater levels at wells with the level for the past 20 years in the upper, middle and lower aquifer layers. Status is reported as either average, below average or above average, figure 157. Wells classified as average are those where the recent level is between the 30th and 70th percentile when compared to the last 20 years. Wells with a level at or above the 70th percentile are classified above average, below the 30th percentile are classified as below average.

Groundwater level trend maps

Trends in groundwater levels for wells in the upper, middle, and lower aquifers and for 5, 10 and 20 years are presented as groundwater level trend maps, figure 157, showing short and long-term changes in groundwater levels and how these patterns vary spatially. Trends are only shown for wells that meet a minimum data requirement. Trend is reported as rising, stable and declining. The threshold for a stable trend is anything within ±10cm/year, which was selected to reflect the typical accuracy of the data.

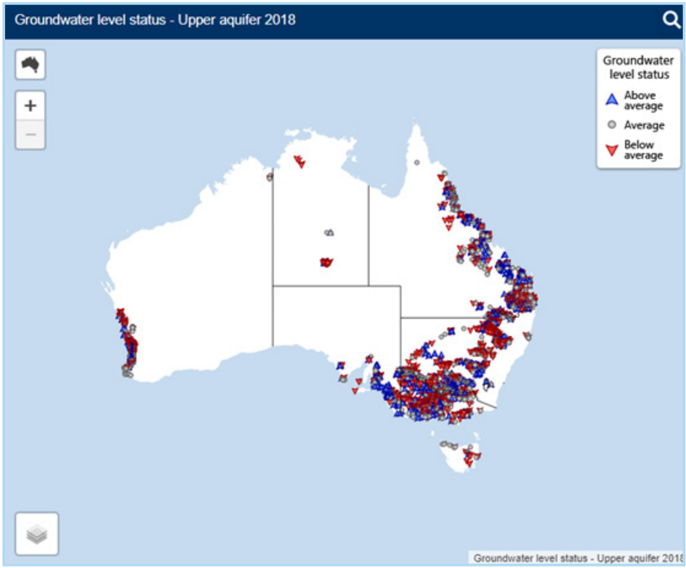

Fig. 157 – Groundwater level status for upper aquifer 2018

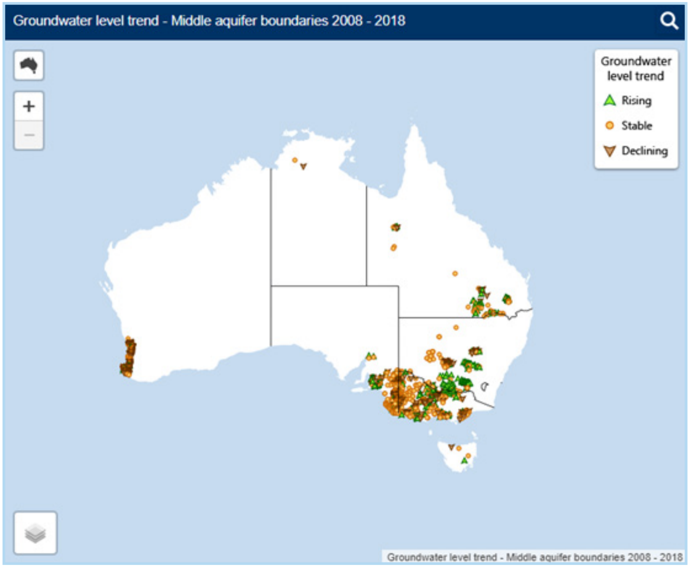

Fig. 158 – Groundwater10 years level trend, for middle aquifers

DISSEMINATION

The Australian Groundwater Insight is a map portal providing access to a wide range of groundwater information, designed for non-experts. The Groundwater Status map and the Groundwater Level Trend maps, described above, are available through this portal.

Moreover, BoM provides several groundwater information products through its website. The data are collected from States and Territories, then processed to be nationally consistent and freely available online. Some of these products are:

Australian Groundwater Explorer – Mapping portal for visualising and analysing groundwater bore data including bore locations and logs; groundwater level data; and salinity and other hydrochemistry measurements. Interactive maps, tables and graphs are used to visualise the information. Data can be downloaded in several formats. Groundwater levels are updated weekly for telemetered bores.

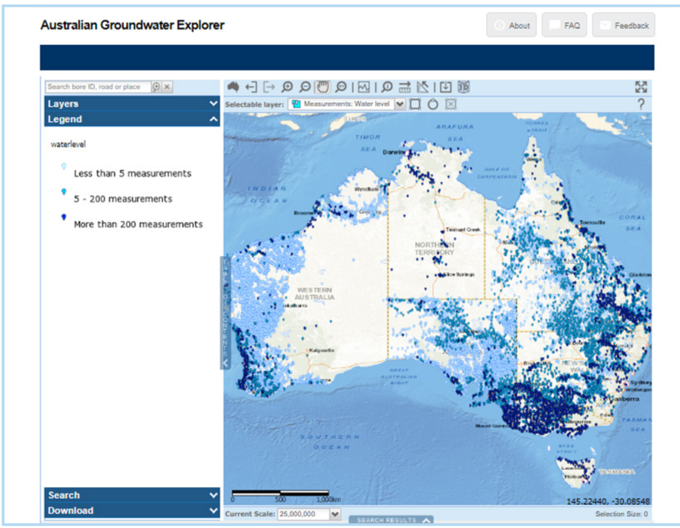

Fig. 159 – Australian Groundwater Explorer Homepage

National Groundwater Information System (NGIS) – Database of spatial information on more than 910,000 wells and their attributes. It has been designed for GIS specialists who need access to the full dataset. Water stakeholders such as water agencies, catchment management authorities, consultants, academics, educational institutions, farmers and private industry use the system for groundwater assessment, accounting and modelling purposes. NGIS data are updated annually.

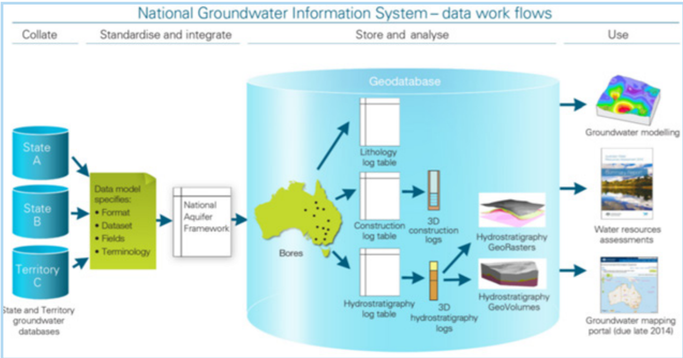

Fig. 160 – NGIS data workflow

Groundwater Dependent Ecosystem Atlas (GDE) – Mapping portal providing a comprehensive national inventory of ecosystems that depend on groundwater. The Atlas is a valuable source of information for experts in government, research and industry sectors who work with ecosystems. It supports the consideration of ecosystem groundwater requirements in natural resource management, water planning and environmental impact assessment.

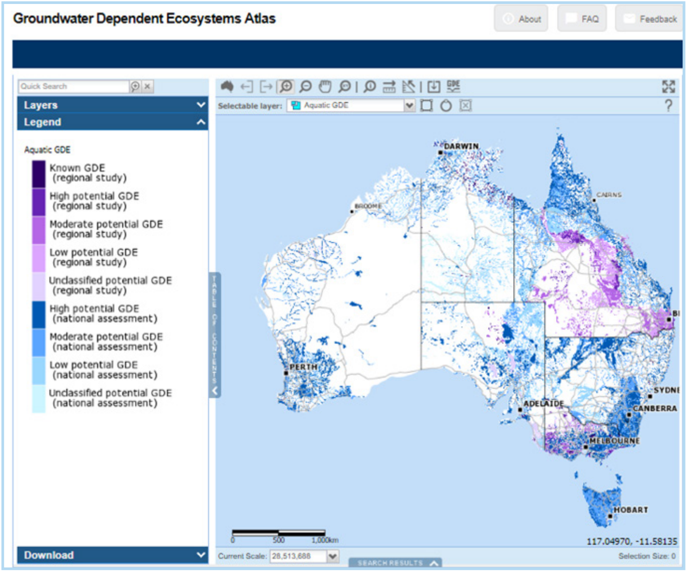

Fig. 161 – Groundwater Dependent Ecosystems Atlas

Sources

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- **Australian Groundwater Insight -** http://www.bom.gov.au/water/groundwater/insight/#/overview/introduction;
- **BOM, Groundwater Information website -** http://www.bom.gov.au/water/groundwater;
- **BOM, Ownership of groundwater data -** http://www.bom.gov.au/water/groundwater/explorer/copyright.shtml;
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- **Groundwater level and trend maps methodology -** http://www.bom.gov.au/water/groundwater/insight/metadata.shtml;
- **Groundwater Provinces across Australia -** http://www.bom.gov.au/water/groundwater/insight/documents/AquiferBoundariesMethod.pdf;
- **Hydrostratigraphy of Australia -** http://www.bom.gov.au/water/groundwater/insight/documents/Hydrostratigraphy.pdf;
- **National Groundwater Information System (NGIS) -** http://www.bom.gov.au/water/groundwater/ngis/; and
- **Victorian Aquifer Framework (VAF) -** https://www.water.vic.gov.au/groundwater/victorias-groundwater-resources/victorian-aquifer-framework.

Bangladesh

Capital city: Dhaka
Inhabitants: 164 Million

INSTITUTIONAL SETTING AND PURPOSE

Several organizations in Bangladesh have established groundwater-level monitoring networks throughout the country, namely: Bangladesh Water Development Board (BWDB), Department of Public Health Engineering (DPHE) and Bangladesh Agricultural Development Corporation (BADC). Barind Multipurpose Authority (BMDA) is a governmental body also in charge of groundwater data collection and monitoring. Amongst them, BWDB is the key organization responsible for monitoring of both surface-and groundwater resources and implementation of water-related development projects in Bangladesh.

The purpose of BWDB's network is to monitor groundwater storage at the national scale in Bangladesh, primarily for the shallow aquifers, besides providing input for national water policy planning and be part of a national climate change monitoring network.

CHARACTERISTICS OF THE NETWORK

The BWDB network has 1,250 monitoring boreholes throughout the country, or one monitoring well per 120 km2. It collects data on groundwater quantity (weekly groundwater levels) and groundwater quality (annual arsenic, salinity, manganese and iron concentrations).

Groundwater level data are collected mainly manually using dippers (groundwater level meters), whereas a few locations are equipped with automatic data loggers.

DPHE has its own network of about 4500 monitoring wells throughout Bangladesh, measuring once a year groundwater levels during the dry season. Readings correspond to the deepest annual groundwater levels in most locations in Bangladesh.

BADC has a network of more than 3000 monitoring wells throughout Bangladesh and published a "groundwater zoning map" for two seasons (at the moment not available online).

BMDA in Rajshahi area has 14,000 deep tube wells (DTWs) for irrigation, and some of them monitor water levels.

Fig. 162 – Dumuria Upazila, Khulna District, Bangladesh, by: Sonia Hoque/REACH

Time-series analyses and spatial mapping are conducted by hydrogeologists working at BWDB.

Groundwater observations from BWDB are not publicly available but they can be purchased directly from BWDB. Additionally, groundwater levels from 2016 for 180 points are available on BADC's website.

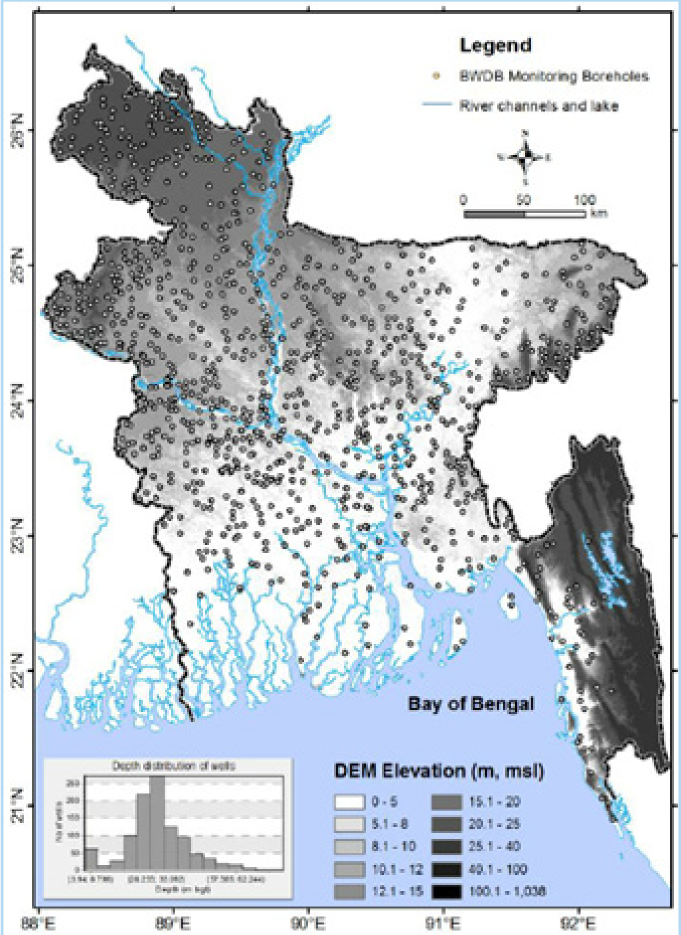

Fig. 163 – Spatial distribution of the BWDB groundwater-level monitoring boreholes in Bangladesh. Source: Shamsudduha, 2013

Sources

- **Bangladesh Agricultural Development Corporation – Groundwater level data** - http://www.badc.gov.bd/site/page/d931c2f2-c016-4bc5-9483-67ca4bb4ea54/-;
- **Bangladesh Water Development Board (BWDB) -** https://www.bwdb.gov.bd;
- **Feedback from BWDB (indirect) -** received on 16-02-2020;
- **Groundwater zoning map from BADC (not available at the moment)** - http://gwv.gisapps.net;
- **Feedback from BWDB (answer to form)** - received in 2019;
- **Shamsudduha, M., 2013** - Groundwater-fed Irrigation and Drinking Water Supply in Bangladesh: Challenges and Opportunities, in: Zahid, A., Hassan, M. Q., Islam, R., Samad, Q.A. (Eds.), Adaptation to Impact of Climate Change on Socio-economic Conditions of Bangladesh. Alumni Association of German Universities in Bangladesh, German Academic Exchange Service (DAAD), Dhaka, pp. 150-169; and
- **SWIBANGLA: Managing salt water intrusion impacts in coastal groundwater systems of Bangladesh. -** Deltares report number: 1207671-000-BGS-0016.

Cambodia

Capital city: Phnom Penh
Inhabitants: 16 Million

INSTITUTIONAL SETTING AND PURPOSE

The Water Resources Management and Conservation Department of the Ministry of Water Resources and Meteorology (MOWRAM) is in charge of managing the groundwater resources in Cambodia.

The main aim of the Ministry is to address scientific and political issues related to domestic and international water resources. There is no clear identification of national groundwater monitoring programme existence. However, several groundwater monitoring initiatives and local networks are present.

PROCESSING AND DISSEMINATION

The MOWRAM has informed that groundwater levels of shallow aquifers are measured in dug wells, where depths varies from 5 to 10 m. Groundwater levels in deep aquifers are measured using tube wells with depths between 30 to 40 m.

Groundwater data are very limited and not well shared. Currently, few institutions are investing in groundwater monitoring, however, the collected data are not publicly available.

One example of collaboration is the partnership between the MOWRAM and the International Water Management Institute (IWMI). They monitor groundwater levels in Prey Veng and Svay Rieng Province.

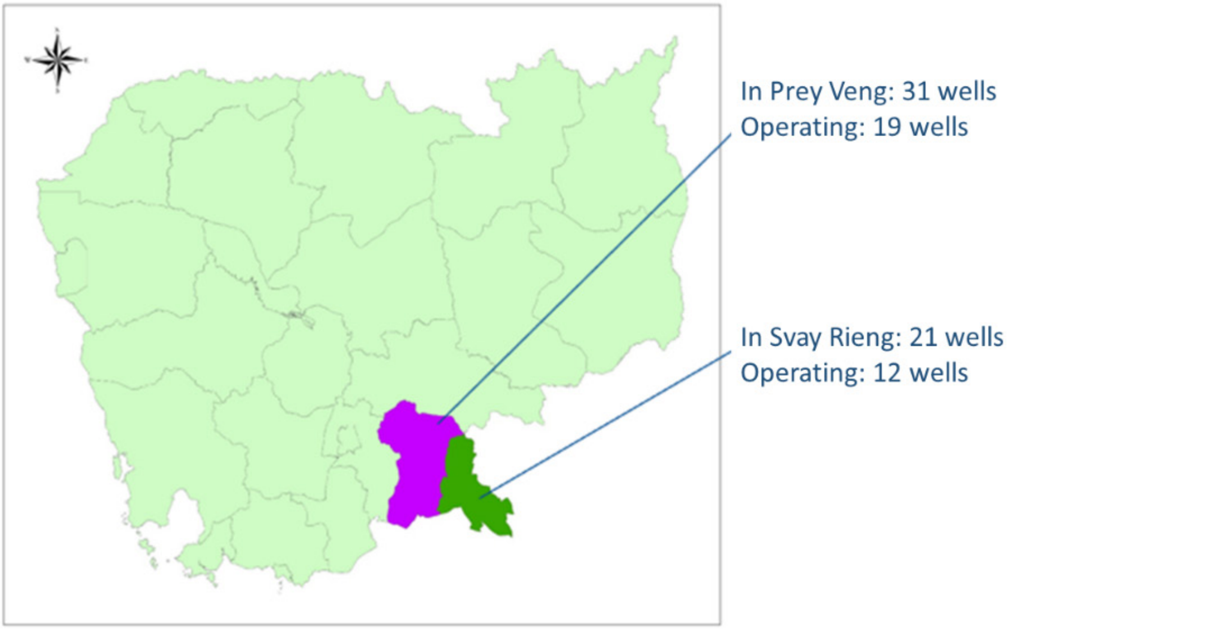

Fig. 164 – Spatial distribution of the BWDB groundwater-level monitoring boreholes in Bangladesh. Source: Shamsudduha, 2013

Sources

- **Cambodia's Ministry of Water Resources and Meteorology (MoWRAM)** - https://www.adaptation-undp.org/partners/cambodia%E2%80%99s-ministry-water-resources-and-meteorology-mowram; and
- **Source: presentation from GGMN workshop** - Thailand 2016.

India

Capital city: New Dehli
Inhabitants: 1377 Million

INSTITUTIONAL SETTING AND PURPOSE

India has a parliamentary form of government which is federal in structure with 37 states and union territories (UTs). Many of these states and UTs have their own groundwater departments and groundwater monitoring mechanisms. At the country level, Central Ground Water Board (CGWB) under the Department of Water Resources, River Development and Ganga Rejuvenation, Ministry of Jal Shakti is the apex organisation dealing with monitoring, assessment and management of groundwater resources. Groundwater monitoring is done by CGWB through its 29 field offices distributed throughout the country with headquarters at Faridabad, Haryana. There is active coordination between the groundwater departments of the States/UTs and the respective field offices of CGWB. The data and information collected as a part of the nation-wide groundwater monitoring programme and other related data help the government of India (the federal government) formulate policies and prioritise areas for management interventions.

CHARACTERISTICS OF THE NETWORK

Groundwater level monitoring network of CGWB consists of nearly 23,000 monitoring stations (CGWB, 2019). Of these 23,000 stations, nearly 16,500 are open dug wells and the remaining 6,500 are purpose-built piezometers (figure 165). While the depths of the open dug wells are mostly around 12 – 15 meters, the depths of piezometers vary from 50 to 300 m. Barring a few high frequency automatic measurements, water levels are measured from these monitoring stations four times a year and the measurements are done manually (steel tapes and sounders). The four-time measurements are done over a fixed period of time throughout the country. Such measurements are done during April/May, August, November, January along with collection of water quality samples during April/May for detailed water quality analysis. The measurement months are chosen as per the existing monsoon pattern in the country.

Under the World Bank assisted National Hydrology Project (NHP) efforts are being made to strengthen the network and automate water level monitoring with real-time/near real-time measurements by addition of more piezometers and installation of around 9000 automatic water level recorders with telemetry across India. Efforts are also being made to integrate monitoring data collected by CGWB and other state governmental organisations for better analysis and understanding of water level behaviour over the country on a single integrated platform.

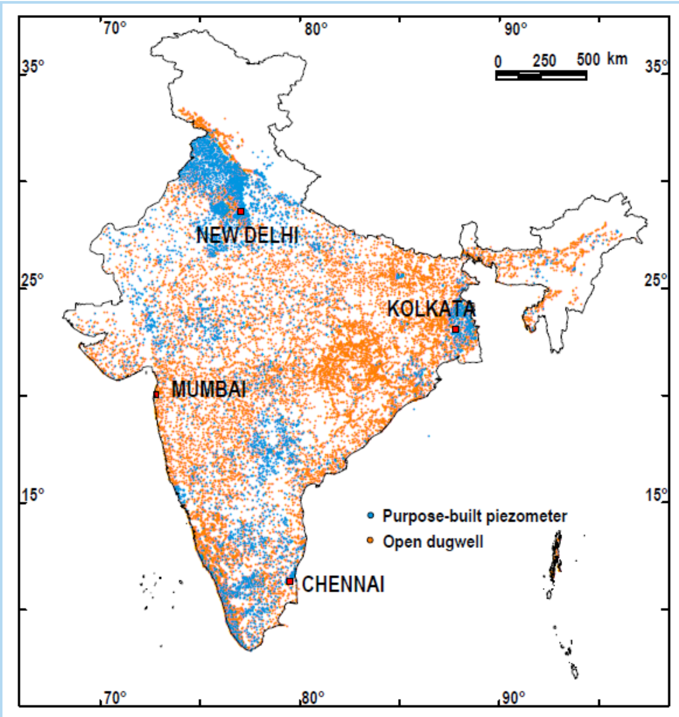

Fig. 165 – Distribution of groundwater monitoring stations (dug wells and piezometers) of CGWB. The blank areas on the north and the north eastern regions are part of the Himalayan terrain

PROCESSING AND DISSEMINATION

CGWB maintains a comprehensive database of water level measurements and groundwater quality done through its monitoring stations over a period of nearly 5 decades. The custom-made software Ground Water Estimation and Management System (GEMS) is used for storage, retrieval and analysis of all kinds of groundwater related data collected by the Board and few State Government organisations, including water level data. GEMS provides facility for statistical analysis, GIS based spatial analysis, timeseries analysis, trend analysis, comparisons, preparation of maps etc. figure 166 shows a sample hydrograph with long term trends generated through GEMS. Results of periodic monitoring are documented and distributed in form of monitoring reports and groundwater year books. These reports are available on the official website of CGWB (www.cgwb.gov.in).

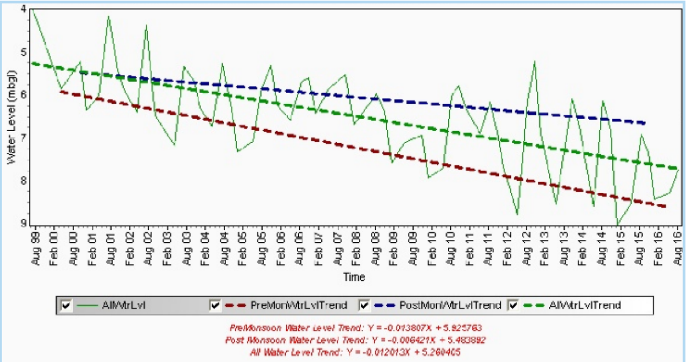

Figure 166 – A sample hydrograph generated from Ground Water Estimation and Management System (GEMS). The hydrograph pertains to the piezometer tapping the deeper aquifer at Dawaleswaram (CGWB, 2017)

Groundwater information in form of maps, hydrographs etc are also disseminated through India Water Resource Information System (India-WRIS), a web-based information system. India-WRIS provides a GIS based interface for visualisation and analysis of water level data. Sample outputs of India-WRIS portal are given in figure 167, figure 168 and figure 169. The user can also overlay available GIS layers like administrative boundaries, basins etc. as per requirement. There is also provision in India-WRIS for downloading validated water level data with geographical coordinates of monitoring stations.

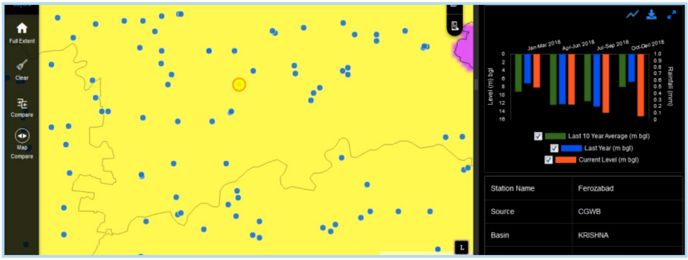

Figure 167 – Sample output of web-based water resource information system of India (India-WRIS) showing comparison of current water level, water level in the previous year and decadal average water level for a selected well

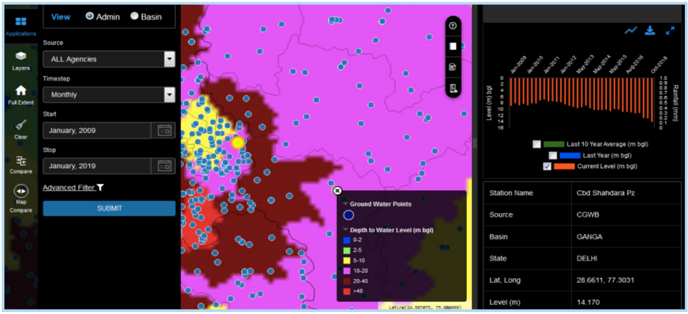

Figure 168 – Sample output of web-based water resource information system of India (India-WRIS) showing long term water levels over a period 2009-2019 for a selected well

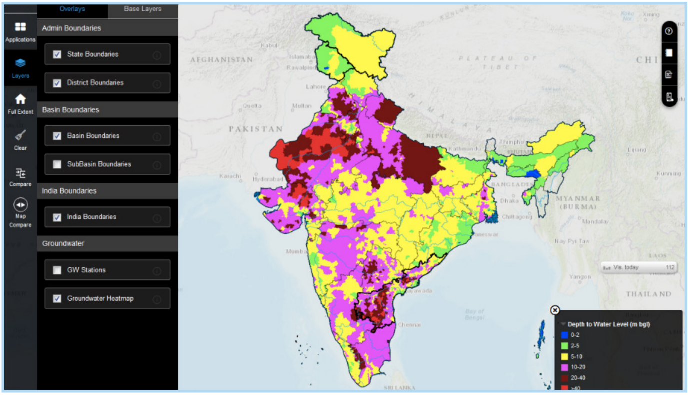

Figure 169 – Sample output of web-based water resource information system of India (India-WRIS) showing spatial variations in depth to water level (groundwater heat map) for Premonsoon (April/May) period 2019

Sources

- **Central Ground Water Board (CGWB), Ministry if Jal Shakti, Department of Water Resources, River Development and Ganga Rejuvenation, Government of India** - http://cgwb.gov.in;
- **Feedback from CGWB** - received on 10-04-2020;
- **CGWB (2019) Ground Water Year Book India 2018-19** - Central Ground Water Board, Department of Water Resources, River Development and Ganga Rejuvenation, Ministry of Jal Shakti, Govt of India, Faridabad;
- **CGWB (2017) Aquifer Mapping and Management of Ground Water Resources, East Godavari, West Godavari and Krishna Districts, Andhra Pradesh. Central Ground Water Board, Southern Region, Hyderabad** - http://cgwb.gov.in/AQM/NAQUIM_REPORT/AP/East%20Godavari,%20West%20Godavari%20and%20Krishna%20Districts,%20Andhra%20Pradesh.pdf;
- **Water Resources Information System, India-WRIS** - http://indiawris.gov.in/wris/#/; and
- **National Hydrology Project (NHP)** - http://nhp.mowr.gov.in/HomeNew/NHPIndexnew.aspx.

Indonesia

Capital city: Jakarta
Inhabitants: 273 Million

INSTITUTIONAL SETTING AND PURPOSE

The Directorate General of Water Resources under the Ministry of Public Works and People's Housing is responsible for the formulation and implementation of policies in the field of water resources management in accordance with the related legislation.

CHARACTERISTICS OF THE NETWORK

The network consists of 51 monitoring wells in Jakarta area, figure 170. The information on the national groundwater monitoring system in Indonesia is not available.

Fig. 170 – Groundwater monitoring wells in Greater Jakarta. Source: Delinom, 2008

PROCESSING AND DISSEMINATION

SIATAB is the Water Information System of Indonesia. Metadata on groundwater monitoring stations for Jakarta are available. The Directorate maintains a groundwater database, figure 171. Data on static groundwater levels, well and pump conditions can be accessed. Groundwater data analysis on the groundwater wells status is presented with pie charts, figure 172.

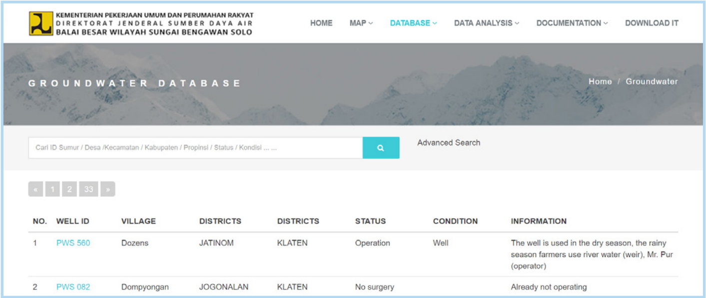

Fig. 171 – Groundwater level status for upper aquifer 2018

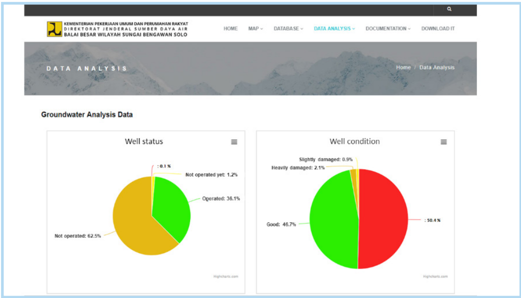

Fig. 172 – Groundwater Well Analysis

Sources

- **Database of Groundwater and Raw Water of the Directorate General of Water Resources** - http://sda.pu.go.id/bbwsbengawansolo/siatab;
- **Database of Groundwater and Raw Water. Groundwater Analysis data** - http://sda.pu.go.id/bbwsbengawansolo/siatab/data_analisis.php?table=sumur;
- **Delinom, R.M. Groundwater management issues in the Greater Jakarta area, Indonesia** - http://doi.org/10.15068/00147302;
- **Ministry for Public Works and Human Settlements, Directorate General of Water Resources** - https://www.pu.go.id/organisasi/ditjen-sumber-daya-air; and
- **Water and raw water information systems, Directorate General of Water Resources** - http://103.122.35.6/siatab.

Iran

Capital city: Tehran
Inhabitants: 83 Million

INSTITUTIONAL SETTING AND PURPOSE

The Ministry of Energy (MOE) and the Ministry of Agriculture (MOA) are responsible for the water resources assessment in Iran. The department of Water Resources Management (WRM), operating under the authority of MOE, is mainly involved in collection of surface and groundwater data, as well as in allocation of water for domestic, industrial and agricultural purposes. Conversely, the MOA is in charge of farm development and irrigation. It regulates the amount of water allocated for agriculture.

In 2014, a groundwater recovery plan was enacted and launched, with the objective of overcoming several problems that Iran has been facing due to the decreasing of groundwater levels in the last 30 years, figure 173.

The plan covers:

- A collaborative management of the groundwater resources;
- Development of a piezometric network including data metering and transferring tools;
- Establishment of a monitoring and recharge control system (flow meters) on water wells;
- Filling and sealing of unauthorized wells.

In 2016, about 12,000 wells have been available to measure the groundwater level every month. Within the recovery plan, it was expected to repair 8,000 wells. Additionally, wells have been provided with online measuring tools. Up to 2016, 50,000 flow meters have been installed to measure abstraction.

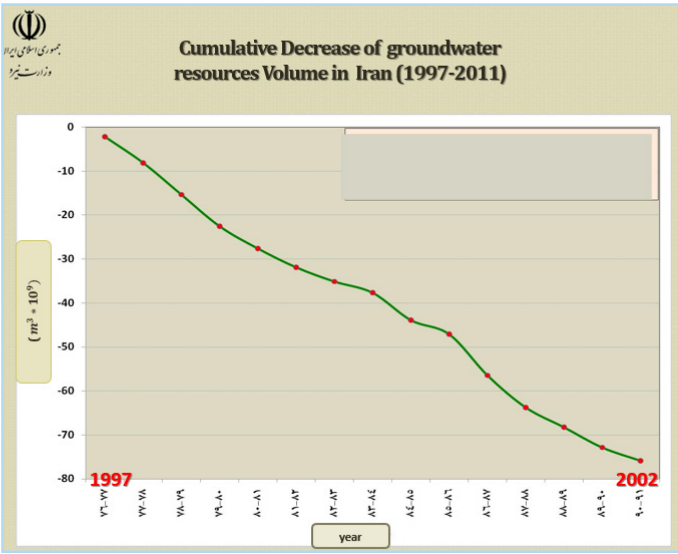

Fig. 173 – Cumulative decrease of groundwater resources volume in Iran (1997-2011)

Fig. 174 – Water Mill on a Qanat in Boshrouyeh, Khorasan, Iran, by: S. Ghiaseddin

Sources

- **Feedback from WRM** - received on 17-03-2020; and
- **GGMN Workshop in Thailand** - 2016.

Jordan

Capital city: Amman
Inhabitants: 10 Million

INSTITUTIONAL SETTING AND PURPOSE

The Ministry of Water and Irrigation (MWI) is the governmental body in charge of the national groundwater monitoring network in Jordan.

The objective of the network is to provide data on the long-term state and trends of groundwater in the country. The network also delivers input to the national water policy planning, regulatory agencies and the public.

CHARACTERISTICS OF THE NETWORK

The network is composed of 252 monitoring wells. Next to groundwater levels, groundwater quality parameters (EC, pH, temperature) are measured as well. Both manual and automatic methods for data collection (data loggers, automatic transmission) are in use.

PROCESSING AND DISSEMINATION

Hydrographs (time series analysis) are produced based on collected data from the monitoring network. Data are used to assess state of water resources and to develop models for prediction. Data are available upon request.

Fig. 175 – River flows through Wadi Mujib near dead sea coastline

Sources

- **Feedback from MWI** - received on 28-05-2020; and
- **Feedback from MWI (answer to form)** - received in 2019.

(Republic of) Korea

Capital city: Seoul
Inhabitants: 51 Million

INSTITUTIONAL SETTING AND PURPOSE

The Ministry of Land, Infrastructure and Transport (MOLIT) implements the assessment of characteristics and available reserves of groundwater and establishes a groundwater management plan for the country. MOLIT is also in charge of establishing nationwide and local groundwater monitoring systems.

Other Ministries sharing the responsibilities in groundwater management are the Ministry of Environment (ME); Ministry of Agriculture, Food and Rural Affairs (MAFRA); Ministry of National Defense (MND); Ministry of The Interior (MOI) and the Ministry of Public Safety and Security (MPSS). The objective of the national groundwater management plan is to conserve and characterize the reserves and amount of exploitable groundwater as well as the conditions for their utilization.

CHARACTERISTICS OF THE NETWORK

Korea has 6 main groundwater monitoring networks: National Groundwater Monitoring Network (NGMN); Groundwater Quality Monitoring Network (GQMN); Seawater Intrusion Monitoring Network (SIMN); Rural Groundwater Monitoring Network (RGMN); Subsidiary Groundwater Monitoring Network (SGMN) and Drinking Water Monitoring Network (DWMN), table 6. They have in total around 3,500 monitoring wells and most of them are equipped with automatic data loggers and remote transfer units. All of them measure water levels, except for GQMN.

Network	Operated by	No. of stations	Frequency
NGMN	MOLIT and K-water	552 (386 deep, 166 of them include shallow)	Every hour
SIMN	MAFRA and the Korea Rural Community Corporation (KRC)	145 monitoring wells (each station has 1 to 3 wells)	Every hour
RGMN	MAFRA and KRC	176	Every hour
SGMN	MOLIT, local governments	1,803	Every hour for automatic systems (60.8%)
DWMN (private data)	ME and commercial bottled groundwater companies	189	Monitoring data has to be submitted to the local government every month

Table 6 – Characteristics of groundwater monitoring networks in South Korea. Source: Lee and Kwon, 2016

The RGMN was established to monitor groundwater changes produced by agricultural activities. The SGMN (or L(Local)GMN) is intended to fill the gaps in the wells from the NGMN, which are sparsely distributed over the country.

Jeju island

Jeju Island has an independent groundwater monitoring network with 132 monitoring wells. Its objective is to protect the groundwater resource from seawater intrusion or anthropogenic pollution. Water levels are measured every hour. Data as water level, water temperature and EC are available to the public on the website: http://www.jeju.go.kr/jejuwater/index.htm

Total number of wells measuring groundwater levels in Korea including the local network in Jeju Island is 2,997.

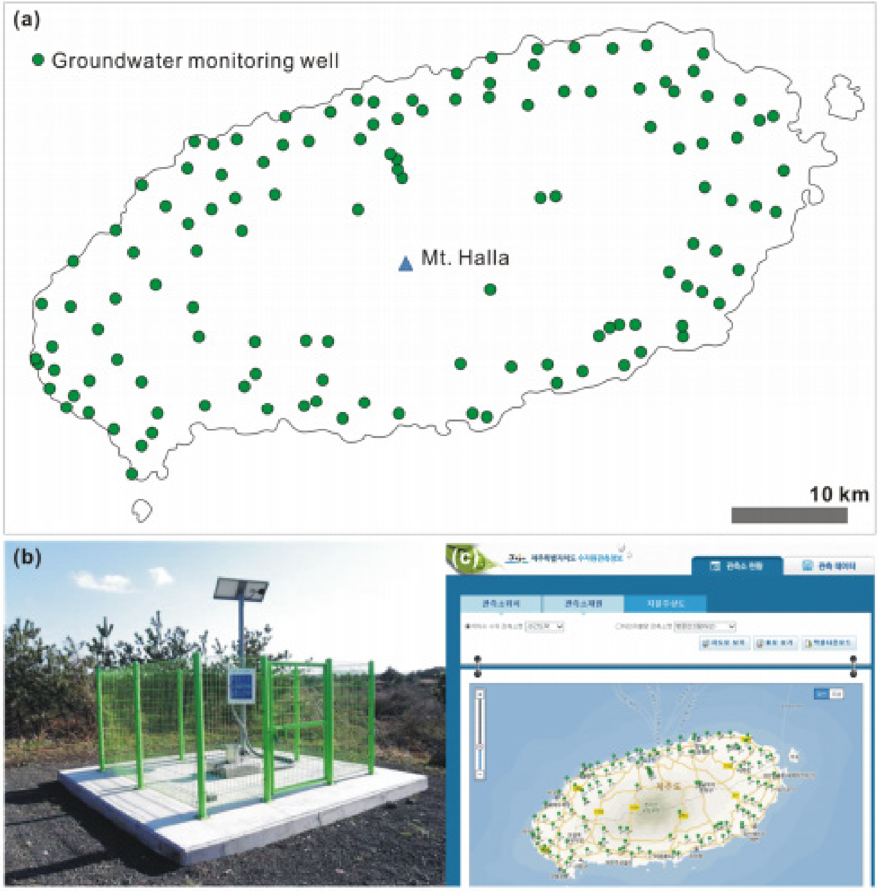

Fig. 176 –Groundwater monitoring network in Jeju Island. (a) Location of monitoring wells; (b) Scene of a monitoring well; (c) Webpage with the real-time monitoring on an hourly basis (currently not available). Source: Lee and Kwon 2016

PROCESSING AND DISSEMINATION

All the monitoring data are stored at the National Groundwater Information Center (NGIC). In 2004, Soil and Groundwater Information System was developed to support installing and operating monitoring networks, including data and information accessibility.

Sources

- **Lee J.-Y., Lee K.-K., Hamm S.-Y., and Kim Y., 2017. Fifty years of groundwater science in Korea: a review and perspective** - http://dx.doi.org/10.1007/s12303-017-0015-7;
- **Jin-Yong Lee J.-Y. and Kwon K. D., 2016. Current Status of Groundwater Monitoring Networks in Korea** - https://doi.org/10.3390/w8040168;
- **Ministry of Environment, Groundwater** - http://www.me.go.kr/eng/web/index.do?menuId=130;
- **Ministry of Environment, Korea Environment Industry Technical Institute. Country Report of Korea (ROK), Soil and Groundwater, 2015. Available in** - https://sgw.epa.gov.tw/Resag/Upload/Files/201704181150303fa1d6.pdf; and
- **Soil Groundwater Information System (SGIS)** - http://sgis.nier.go.kr.

Malaysia

Capital city: Kuala Lumpur
Inhabitants: 31.5 Million

INSTITUTIONAL SETTING AND PURPOSE

The Department of Mineral and Geoscience Malaysia (JMG), formerly known as the Geological Survey Department, is the lead agency responsible for matters related to groundwater exploration, tube well development and groundwater data inventory in Peninsular Malaysia, Sabah and Sarawak.

JMG actively participates in international cooperation and is committed in fulfilling obligations set by global frameworks such as CCOP Geoinformation Sharing Infrastructure for East and Southeast Asia. JMG is currently involved in the CCOP-GSJ-GSi Groundwater Phase IV project, which mainly focus on management of groundwater database within CCOP member countries.

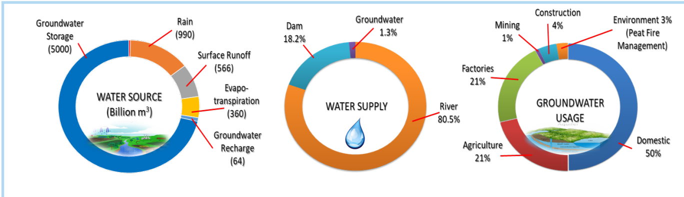

Fig. 177 – Groundwater status in Malaysia (National Water Resources Study (NWRS), 2012)

CHARACTERISTICS OF THE NETWORK

Since the beginning of the 5th Malaysia Plan in 1986, 4,758 tube wells (figure 178) have been developed by JMG for various purposes which benefited 1.5 million people nationwide. JMG has also developed a groundwater database known as HYDROdat and a GIS application known as HydroGIS, for planning, assessing and monitoring activities to safeguard and maintain the quality and potential reserve of groundwater.

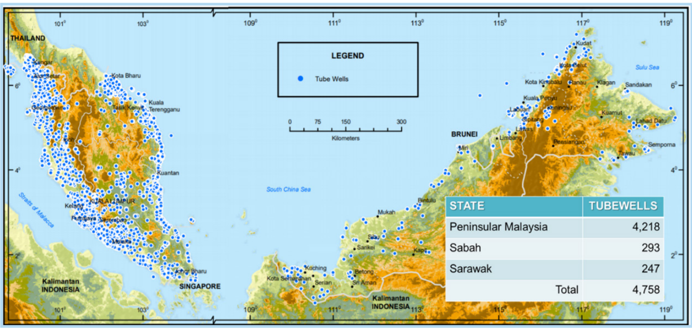

Fig. 178 – Tube well location map in Malaysia (JMG HYDROdat, 2018)

Groundwater levels and groundwater quality are monitored at selected wells on a periodic basis, generally twice a year. Field samplings measuring temperature, conductivity and dissolved oxygen are designed for dry (Aug-Oct) and rainy (Jan-Mar) seasons. Two types of wells are used: cluster type that allows sampling of groundwater at various depths, and individual wells that were mainly exploration wells and later converted to monitoring wells. Data gathered from the field samplings will be keyed into HYDROdat and the well locations will be plotted using HydroGIS.

JMG has outlined several new initiatives in line with requirements of the 12th Malaysia Plan and to resolve existing groundwater issues. The 12th Malaysia Plan is critical to implement water sector transformation through mainstreaming groundwater usage for water security and economic growth. Hence, JMG needs to restructure and update the existing groundwater database and monitoring system. The current groundwater database system (HYDROdat) will be upgraded to enhance its capabilities in groundwater evaluation and risk assessment management.

Concurrent to the upgrading of HYDROdat, JMG is working diligently to set up a National Groundwater Monitoring System (NaGMiS); an integrated groundwater monitoring network collaboration with the relevant local agencies and stakeholders. NaGMiS will provide more groundwater data collection and enhance the data coverage comprehensively for a better and more holistic management of groundwater resources.

Sources

- **Department of Mineral and Geoscience Malaysia**;
- **Feedback from Dept. of Mineral and Geoscience Malaysia (Putrajaya)** - received on 10-07-2020; and
- **GGMN South East Asia Workshop** - 2016.

Myanmar

Capital city: Napypyidaw
Inhabitants: 53.7 Million

INSTITUTIONAL SETTING AND PURPOSE

The Ministry of Agriculture, Livestock and Irrigation (MOALI) is in charge of promoting inclusive and sustainable agriculture. The Ministry also implements Water Use and Management policy with the aim to ensure access to high quality water by using groundwater without damaging the environment and water resources.

In Myanmar there is no national groundwater monitoring network. However, establishment of the network is in progress by the Irrigation and Water Utilization Management Department (IWUMD) with its Groundwater Division.

CHARACTERISTICS OF THE NETWORK

In 2017 Myanmar started with the establishment of nine monitoring stations: 1 station in Sagaing, Bago, Yangon, Ayeyarwaddy and Mon, 2 in Mandalay, 2 in Magway, figure 179.

The observation wells are well protected, and the data are measured by automatic data loggers. 58 monitoring station in the Central Basin and 22 in remote areas were planned to be set for the groundwater monitoring in 2017.

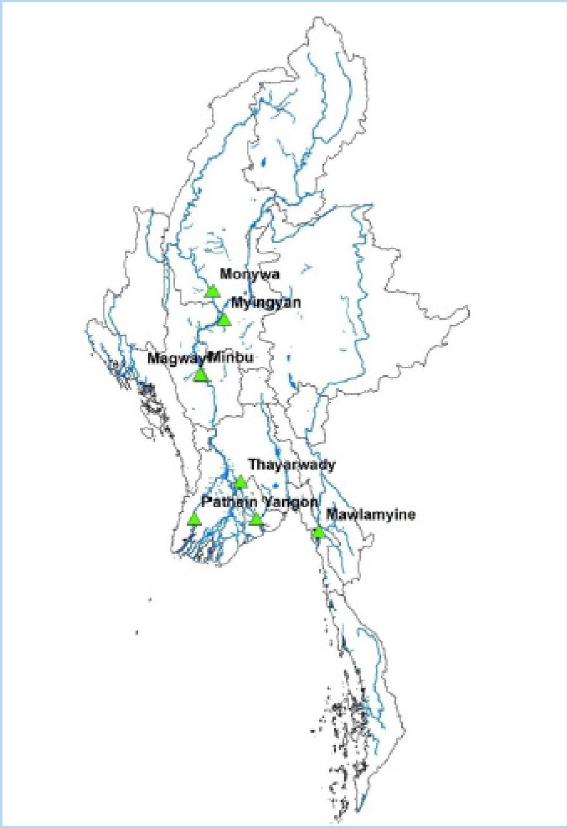

Fig. 179 – Pilot groundwater monitoring stations in Myanmar

Sources

- **FAO, 2016** - http://www.fao.org/nr/water/aquastat/countries_regions/MMR/index.stm;
- **MOALI** - https://www.moali.gov.mm/en/content/about-ministry;
- **Presentation GGMN** - workshop 2016; and
- **Presentation Ministry of Agriculture, Livestock and Irrigation, Irrigation and Water Utilization Management Department (MOALI)** - March 2017.

Nepal

Capital city: Kathmandu
Inhabitants: 28 Million

INSTITUTIONAL SETTING AND PURPOSE

The Groundwater Resources Development Board (GRDB) under the Ministry of Energy, Water resources and Irrigation is the primary agency from the government responsible for groundwater survey, monitoring and development.

The Kathmandu Valley Water Supply Management Board (KVWSMB) was established by the Government of Nepal as the institution responsible for groundwater regulation and management in Kathmandu Valley. KVWSMB was created to address overlaps in responsibilities between GRDB and the Water and Energy Commission Secretariat (WECS), who is in charge of performing water resource functions at a general level. KVWSMB is responsible for groundwater data collection and processing, groundwater development planning, monitoring, regulation and research.

CHARACTERISTICS OF THE NETWORK

Continuous groundwater monitoring started in 1999 in the Kathmandu Valley, with 50 monitoring wells (8 in shallow and 42 in deep aquifers) under the project "Urban Water Supply Reforms in Kathmandu Valley". After the project was finished, the Groundwater Resources Development Project (GRDP) (implementing agency of GRDB) continued the monitoring.

Fig. 180 – Kathmandu Valley by Aleksandr Zykov

Sources

- **Gautam D. and R. N. Prajapati R. N., 2014. Drawdown and Dynamics of Groundwater Table in Kathmandu Valley, Nepal. The Open Hydrology Journal, 8, 17-26** - https://benthamopen.com/contents/pdf/TOHYDJ/TOHYDJ-8-17.pdf;
- **Shrestha S., Pradhananga D., Pandey V.P. (Eds.) (2012). Kathmandu Valley Groundwater Outlook. Asian Institute of Technology (AIT), The Small Earth Nepal (SEN), Center of Research for Environment Energy and Water (CREEW), International Research Center for River Basin Environment-University of Yamanashi (ICRE-UY). Section II: Groundwater Quantity** - http://people.ucalgary.ca/~hayashi/kathmandu_2016/reading/Shrestha_etal_2012_KVGW.pdf.

New Zealand

Capital city: Wellington
Inhabitants: 4.9 Million

INSTITUTIONAL SETTING AND PURPOSE

The Ministry for the Environment is responsible for setting national level legislation and regulation on water quality and activities that can impact it. Operational management of groundwater resources is undertaken by local government. Regional councils, of which there are 11 in New Zealand, are responsible for managing water quality and quantity, including activities which can affect aquifers. City councils are responsible for providing clean drinking water, and there are 6 unitary authorities which provide both functions of the regional and city councils.

The Ministry for the Environment periodically reports on the national state of different aspects of the environment, including freshwater and groundwater quality. Nationally, groundwater quality is assessed using the indicators ammoniacal nitrogen, chloride, dissolved reactive phosphorus, chloride, conductivity and Escherichia coli. The latest national report on freshwater was published in 2020.

Central government also provides funding for regional or national scale research to get a better understanding of groundwater resources in New Zealand. For example, a study published in 2019 was undertaken to classify different geological units at a national level in terms of their importance for groundwater flow and storage, as shown in figure 181. Other national level research includes funding for the National Groundwater Monitoring Programme, a long-term research and monitoring programme run in collaboration with all of New Zealand's regional authorities. The "Our Land and Water" National Science Challenge, is another funding avenue. This is a contestably funded research initiative, which funds research on New Zealand's freshwater resources with a particular focus on enhancing the productivity of New Zealand's primary sector.

CHARACTERISTICS OF THE NETWORK

National institutional arrangements require that each Regional Council or Unitary Authority have their own groundwater monitoring programme. The extent of the different monitoring networks varies across regional councils, depending on their size and available resources, as well as the requirements set forth in their Regional plans. However, all regions will have some monitoring of water quality, groundwater resource allocation and groundwater levels. The example of the Tasman District Council is described below.

The district council of Tasman monitors groundwater levels in all major aquifers in the district. The levels are registered at each site every fifteen minutes with data loggers. Currently, Tasman District has 50 automated groundwater level monitoring sites, and the data of these sites are available in real time via telemetry network, figure 182.

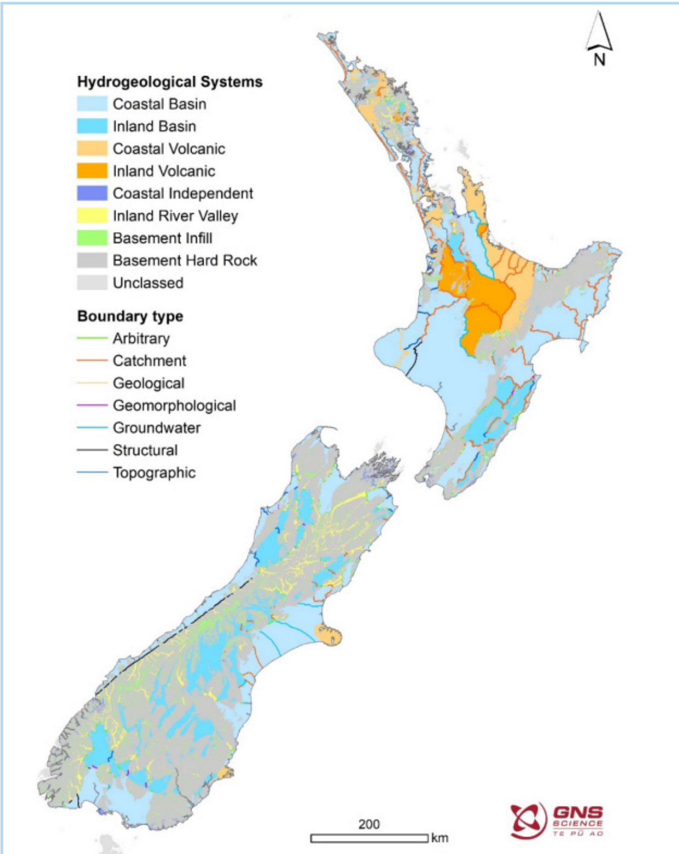

Fig. 181 – National map of hydrogeological systems (from Moreau et al, 2019, and provided by the Ministry for the Environment)

PROCESSING AND DISSEMINATION

The Council publishes two groundwater level graphs: for 7 and 30 days, figure 183. The groundwater levels are analysed as minimum, maximum and average levels and presented in a table format on the website of the Tasman District Council, figure 184.

Groundwater History

Aquifer: Arthur Marble Aquifer

Catchment: Takaka

Zone: Takaka

Period of analysis: 25 August 1999 to 31 December 2016

Comment: This well is located in the recharge part of the Arthur Marble Aquifer (unconfined) in the central Takaka valley. This well provided long term information on the recharge to the Arthur Marble Aquifer and consequently flows in Te Waikoropupū Springs.

	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Min level (m)	19.19	22.55	20.62	19.50	20.52	26.63	34.26	31.98	33.98	33.71	21.63	19.39
Year it occurred	2016	2015	2006	2010	2001	2008	2013	2013	2011	2015	2005	2016
Max level (m)	44.98	44.60	46.03	47.26	48.43	47.71	46.51	46.13	44.71	45.38	47.05	48.68
Year it occurred	2012	2004	2016	2014	2011	2003	2003	2010	2012	2011	1999	2011
Average	36.08	35.17	34.46	35.80	37.94	40.49	40.52	40.25	40.05	40.19	38.16	36.58

This table shows the minimum and maximum water levels recorded each month and the year the extreme value was reached during the stated analysis period.

Fig. 182 – Groundwater level analysis of the Tasman District Council

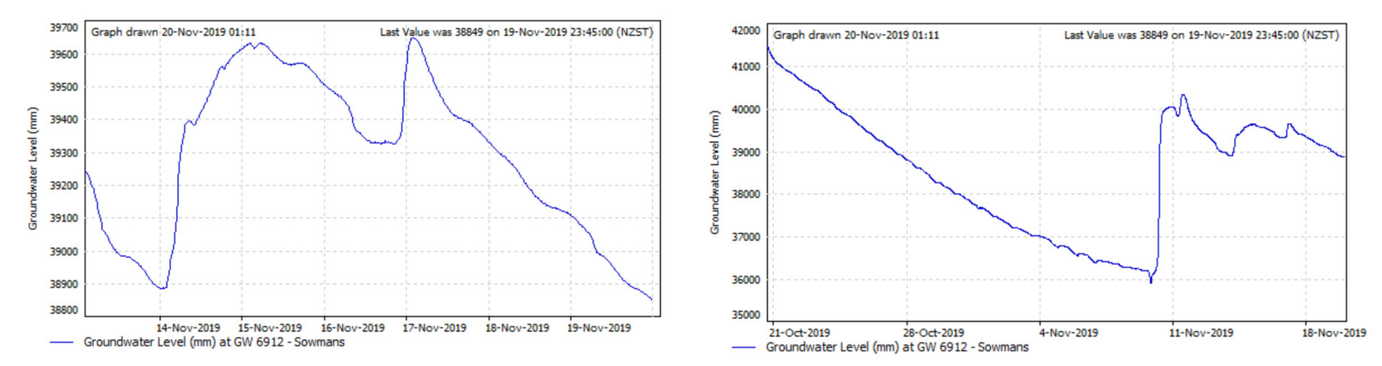

Fig. 183 – Groundwater Level for last 7 and 30 days at Arthur Marble Aquifer at Sowmans

Click on the map markers or links below to find up-to-date information on groundwater levels in Tasman District.

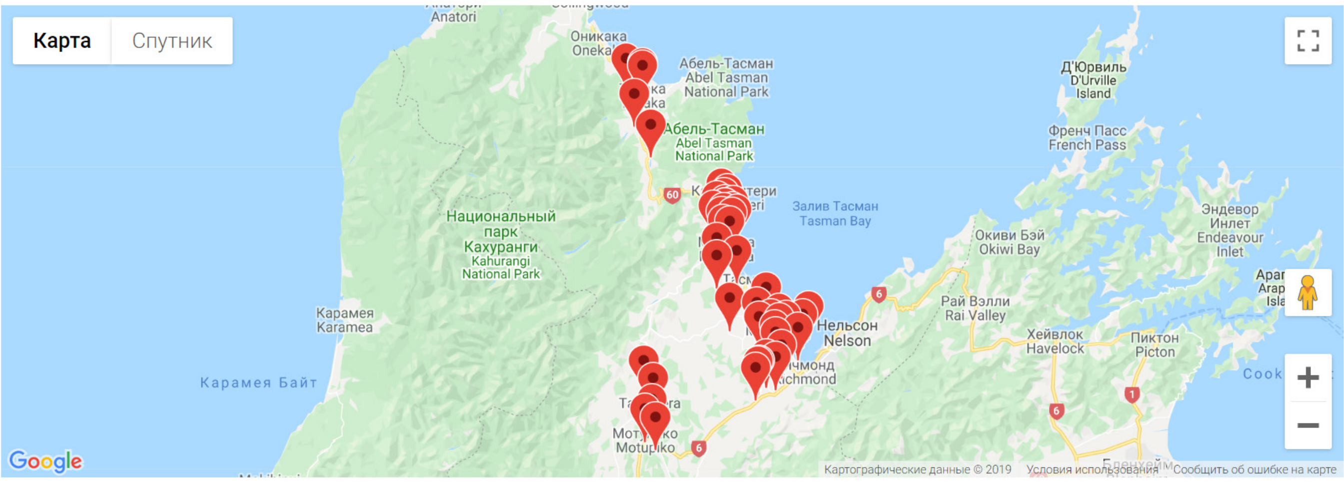

Fig. 184 – Groundwater level analysis of the Tasman District Council

Sources

- **Feedback from the Ministry for the Environment** - received on 01-10-2020;
- **Ministry for the Environment, Our freshwater 2020 Report** - https://www.mfe.govt.nz/publications/environmental-reporting/our-freshwater-2020;
- **Ministry for the Environment, New Zealand groundwater atlas** - hydrogeological-unit map of New Zealand: https://www.mfe.govt.nz/publications/fresh-water/new-zealand-groundwater-atlas-hydrogeological-unit-map-of-new-zealand; and
- **Tasman District Council, Groundwater levels** - https://www.tasman.govt.nz/my-region/environment/environmental-data/groundwater-levels.

Pakistan

Capital city: Islamabad
Inhabitants: 212.2 Million

INSTITUTIONAL SETTING AND PURPOSE

The Ministry of Water Resources takes the lead on behalf of the Federal Government for development of the water sector. In this regard, the Scarp Monitoring Organization (SMO) is working under the Umbrella of the International Waterlogging and Salinity Research Institute (IWASRI) of the Water and Power Development Authority (WAPDA).

The Water and Sanitation Agency (WASA) of several major municipalities carry out some groundwater monitoring within urban centres but this does not extend to rural or agricultural areas (Bhatti et al, 2016). In addition to WASA's groundwater monitoring within urban cities, Pakistan Council of Research in Water Resources (PCRWR), Islamabad, is also working on the observation of water table depth. Moreover, the Geological Survey of Pakistan conducts work on groundwater resources exploration.

Provinces may have their own groundwater monitoring programme, as the one from the Directorate of Land Reclamation (DLR) of the Punjab Irrigation Department.

CHARACTERISTICS OF THE NETWORK

Since 1968, SMO conducts hydrological monitoring pre and post monsoon (depth to water table and water quality) biannually in the Indus Basin Irrigation System (IBIS).

Compared to other provinces of Pakistan, the DLR of the Punjab Irrigation Department has a much more systematic groundwater monitoring program with 3,000 observation wells. DLR measures the water levels in piezometers manually, twice a year.

PROCESSING AND DISSEMINATION

Data collected in approximately 9000 observation wells in Punjab and 3000 in Sindh from 49 canal commands of Punjab, Khyber Pakhtunkhwa, Sindh and Balochistan provinces is analysed by SMO and maps are developed using GIS.

The interactive map on the website of Punjab Irrigation Department (https://irrigation.punjab.gov.pk/) presents the aquifer status of last two pre and post monsoon seasons from 2013 till 2018. The depth of the groundwater level is indicated in feet. By changing pre- and post-monsoon periods, it is possible to see the fluctuation of the groundwater level. However, neither time-series not download of data is available.

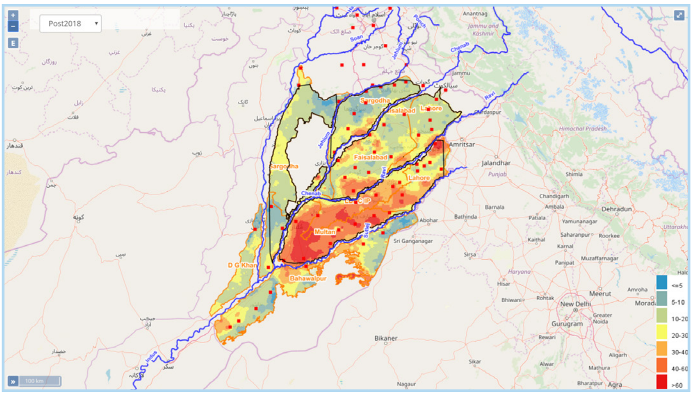

Fig. 185 – Groundwater monitoring in Punjab post 2018

Sources

- **Feedback from the Ministry of Water Resources** - received on 10-11-2020;
- **Punjab Irrigation Department** - https://irrigation.punjab.gov.pk/;
- **Year book 2018-19, Geological Survey of Pakistan** - https://www.gsp.gov.pk/images/year-book-2018-19-pdf-final.pdf; and
- **Ministry of Water Resources, Government of Pakistan** - http://mowr.gov.pk/.

Thailand

Capital city: Bangkok
Inhabitants: 69.4 Million

INSTITUTIONAL SETTING AND PURPOSE

The Department of Groundwater Resources (DGR) is responsible for the quantity and quality assessment of groundwater, as well as for the development of protection requirements to support groundwater management. Some of the specific tasks of the DGR are the selection of sampling sites, the analysis and transfer of data.

The objective of the national monitoring programme of Thailand is to identify spatial and temporal trends and to understand the causes of change of the groundwater status.

CHARACTERISTICS OF THE NETWORK

The groundwater monitoring network of Thailand started its operation in 1977. Nowadays it has a total of 1,312 stations encompassing about 2,535 wells. One station included approximately 2 to 8 wells.

Groundwater levels are recorded both manually and automatically. Groundwater quality sampling is performed twice a year. Recently, DGR developed a mobile phone application to assist data collection.

Collected metadata are name and location of the well, ground surface elevation, date of measurement, depth to groundwater, elevation of groundwater surface, note of well status (pumping or not pumping) and any surrounding conditions that might affect groundwater levels. Moreover, a reference point is checked to assure consistency in the measure of groundwater depth.

Fig. 186 – Protection of the observation well (left) and the process of reading the measurements (right)

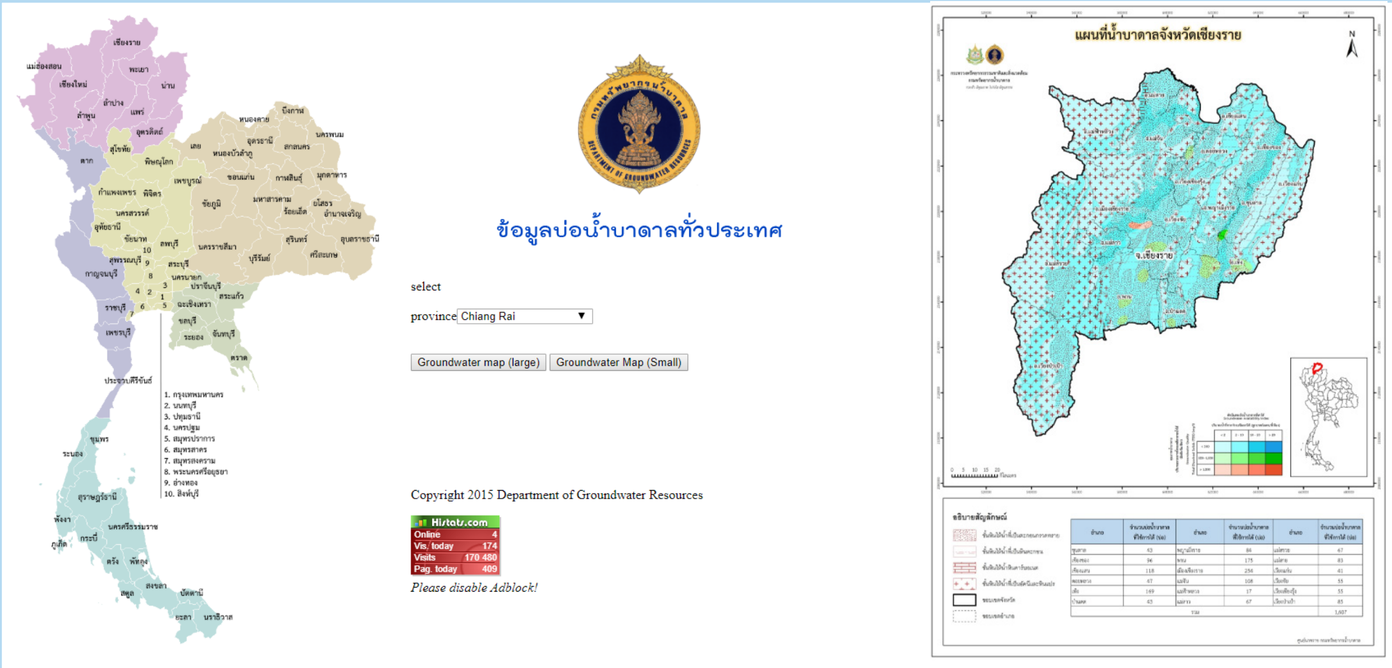

Fig. 187 – Groundwater well map in Thailand. Source: Groundwater Resources Information System Group

Groundwater level data are used to make Groundwater level maps (potentiometric surfaces) and maps to represent the changes in groundwater levels. DGR website has a section for groundwater level and status. Currently, DGR manages the Thailand Groundwater Monitoring System (TGMS) (in Thai, link in Sources).

Data are also stored in the Pusuthara Information System (in Thai), where people can register to search, capture and store data. Spatially distributed data (GIS) are also available. The system consists of the Pasuthara database, a portal for groundwater surveillance and monitoring at remote stations and various information portals: for groundwater control, groundwater management in groundwater crisis areas and for conjunctive use.

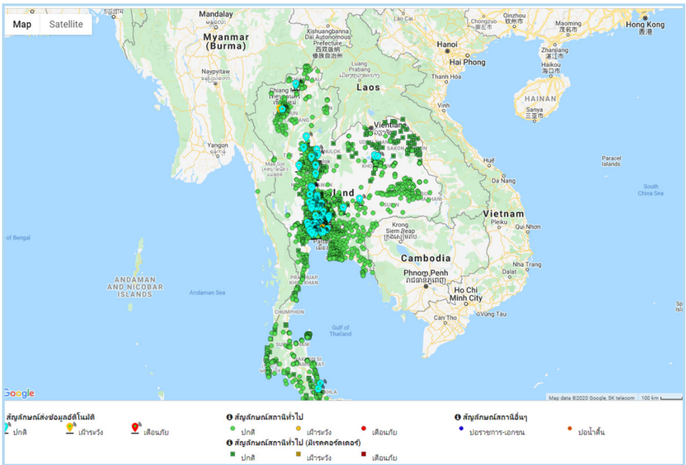

Fig. 188 – Thailand Groundwater Monitoring System (TGMS). Source: DGR.

Sources

- **Department of Groundwater Resources** - http://www.dgr.go.th/th/public-service/36;
- **Department of Groundwater Resources, Public service** - http://www.dgr.go.th/th/public-service/41;
- **Feedback from the Department of Groundwater Resources** - received on 09-10-2020;
- **GGMN South East Asia Workshop** - 2016;
- **Groundwater Resources Information System Group, 2015** - http://app.dgr.go.th/newpasutara/xml/Krabi.files/show3.php?d-dlGeo=45&btn2=;
- **Ministry of Agriculture, Livestock and Irrigation. Irrigation and Water Utilization Management Department. Presentation on Pilot Project of Groundwater Monitoring in Myanmar (includes information about Thailand)** - https://www.dwir.gov.mm/images/world-water-day/05_GW%20Monitoring%20in%20Myanmar_U%20Thant%20Zin.pdf; and
- **Thailand Groundwater Monitoring System (TGMS)** - http://tgms.dgr.go.th/#/home.

Vietnam

Capital city: Hanoi
Inhabitants: 95.5 Million

INSTITUTIONAL SETTING AND PURPOSE

The Ministry of Natural Resources and Environment (MONRE) performs the function of state management in the fields of land, water resources, mineral resources and geology; environment, meteorology and hydrology; climate change surveying and mapping, integrated management of natural resources, and protection of sea and island environment. As a part of MONRE, the National Centre for Water Resources Planning and Investigation (NAWAPI) is in charge of groundwater monitoring.

CHARACTERISTICS OF THE NETWORK

Water resources monitoring systems have been developed since 1980s. In 2020, 946 monitoring wells were part of the National Groundwater Monitoring Network of Vietnam, covering aquifers in the Northern Region, North Central Region, Central Highlands, South Central Coast and Southern Region, figure 189. The collection of data is carried out manually and automatically, with more than 50% of the wells working automatically.

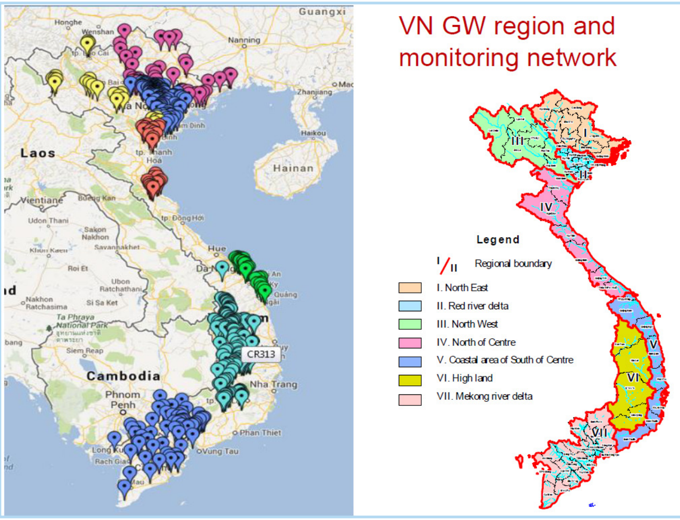

Fig. 189 – Groundwater monitoring network in Vietnam. Source: Ministry of Agriculture, Livestock and Irrigation of Myanmar, March 2017, GGMN workshop

The automatic monitoring gauges are capable of monitoring and automatically transmitting data according to pre-set programs. Data is connected and transmitted via GSM/GPRS/3G/4G mobile networks. Through the use of automatic recording gauges and modern data transmission technology mentioned above, the observed data is always ensured synchronous, economical, accurate and timely, making an important contribution to the results and topicality of water resources forecasts and warning bulletins.

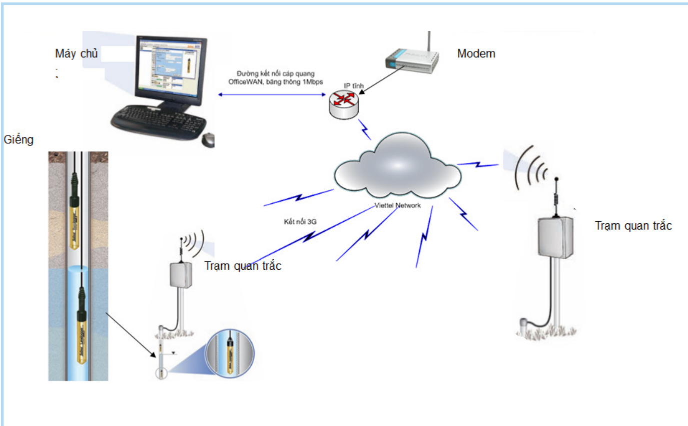

Fig. 190 – Flowchart of automatic monitoring technology (Source: MONRE)

PROCESSING AND DISSEMINATION

Data from the field is automatically transferred to the National water resource database developed by NAWAPI, figure 191. The database was established on the basis of modern technology for storage, unified management, and information sharing and exploitation, which improves cooperation among state agencies and makes a practical contribution to the socio-economic development.

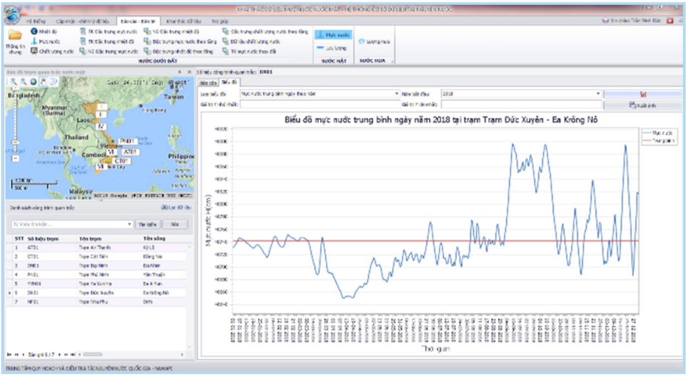

Fig. 191 – National database software interface (Source: MONRE)

NAWAPI's database has been put into operation with the task of creating a convenient system for receiving, storing, sharing and exploiting information and data for multiple purposes, in a multidisciplinary way. In the future, the database will be fully integrated with the monitoring systems to be able to access and exploit real-time data.

On the other hand, there is a decentralized monitoring data management system working nationwide, figure 192. The system provides and supports management tools as well as several types of monitoring data for different management, planning and information needs of society. The system provides data and information on water resources, forecasts and warnings throughout the country, and helps people and businesses to promptly and effectively access to them.

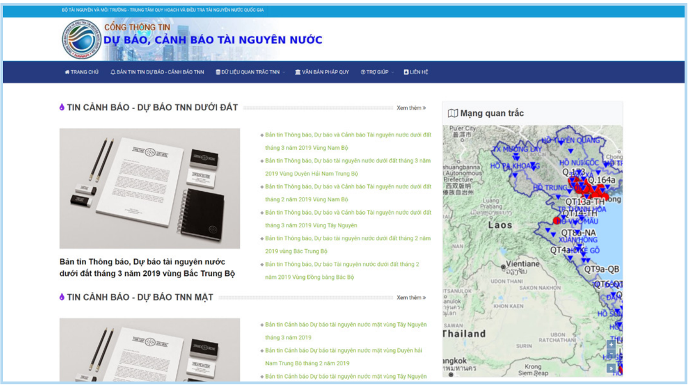

Fig. 192 – Real-time water monitoring, forecasting and warning data portal operated by NAWAPI

Regarding simulation and computation, NAWAPI invested in one high-performance computer system, including two head node servers, two broker servers, twelve workstation computers, one central storage system, 38 workstations, and three monitors, to improve the quality of simulation and calculation for water resource warning forecasting. In addition, in the field of water quality analysis, NAWAPI also invested in a laboratory with modern analytical equipment with a high level of automation to facilitate observation and analysis of water quality.

In order to improve the quality of water resources warning and forecasting, NAWAPI has built and applied the MO operational system, which integrates models of hydrology, hydraulics, water balance and groundwater, in simulation and prediction works. In particular, this system has modules that allow the construction and management of simulation scenarios, real-time calculations with automatic connection to import, process data, run simulation models, and show results. Moreover, the system can compare scenarios and perform sensitivity analysis, as well as model optimization. Associated models in the MO system are licensed and updated regularly. The MO system can produce forecasts and warnings applied to groundwater resources (monitoring water levels and supporting decision making) in 5 regions (Northern Region, North Central Region, Central Highlands, South Central Coast and Southern Region). In addition, NAWAPI has also applied, combined and converted a number of mathematical models, as the conversion of a numerical model from GMS to Feflow and the calculation of saline intrusion in the Mekong Delta using GMS.

Groundwater data collected through the national monitoring network are stored in NAWAPI's database. Timeseries of groundwater parameters can be downloaded from the web portal, by request only. Monthly, quarterly and yearly notifications, warnings and forecasts are regularly published for localities and people in a timely manner. Those newsletters can also be downloaded easily through the NAWAPI's website and its portal dedicated for water monitoring and forecasting (see links in Sources section).

Sources

- **Feedback from NAWAPI, MONRE** - received on 29-09-2020;
- **GGMN workshop in Thailand** - 2016;
- **NAWAPI's website (1)** - http://www.nawapi.gov.vn/index.php;
- **NAWAPI's website (2)** - http://123.16.176.41/nawapinew/ (newsletters);
- **NAWAPI's water monitoring and forecasting portal** - http://123.16.176.41/lawis/public; and
- **MONRE main website** - http://www.monre.gov.vn/English/Pages/Home.aspx.

NATIONAL GROUNDWATER MONITORING PROGRAMMES

A GLOBAL OVERVIEW OF QUANTITATIVE GROUNDWATER MONITORING NETWORKS

Groundwater is a vital natural resource, being increasingly under pressure of climate change and human activities. We need to monitor the invisible groundwater in order to use and protect it properly.

This document provides an overview of quantitative groundwater monitoring networks at national scale. It is prepared to encourage sharing of monitoring experience, assist in improvement of monitoring and data processing and increase awareness of a general lack of groundwater monitoring.

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International Groundwater Resources Assessment Centre