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STATE OF GLOBAL WATER RESOURCES

UPDATED METHODOLOGY FOR REPORTING ON GROUNDWATER LEVELS

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# Introduction

Groundwater constitutes the primary reservoir of non-frozen potable water on Earth, exhibiting a close hydrological linkage with surface water. Information on the quantitative and qualitative status of aquifers is essential for strategic water resources planning, effective management, and for policy-making. Access to this information on a regular and timely basis is crucial because the stress on groundwater resources is increasing, due to the rise in water demand, pollution, and the effect of climate change on water availability. The dissemination of such information and the underlying data is a prerequisite for the active participation of communities and other stakeholders in the management of groundwater, which is itself a condition for effective groundwater management (FAO, 2016[[1]](#footnote-1)).

Groundwater monitoring is essential to produce information on the quantitative and qualitative status of aquifers. Developing and maintaining groundwater monitoring networks can be challenging, in particular in low-income countries. There are also countries where groundwater monitoring data are collected but not shared. Nevertheless, monitoring networks are operational in many parts of the world (IGRAC, 2020[[2]](#footnote-2)) and serve as a basis to report on the state of groundwater resources, such as in Europe, under the Water Framework Directive (WFD), in India, or in California, under the Sustainable Groundwater Management Act (SGMA). Under SDG indicator 6.3.2 (*Progress on ambient water quality*), countries report on the qualitative status of their groundwater bodies, based on measurements of several groundwater quality variables. There is however no equivalent indicator to report on the quantitative status of groundwater bodies under the SDGs.

Groundwater monitoring data collected in the countries can also support groundwater assessment studies at the global level. Since 2022, the World Meteorological Organization publishes a yearly report on the State of Global Water Resources[[3]](#footnote-3). In the second edition, IGRAC contributed to a new section on Groundwater Levels. The section contained an assessment of groundwater resources based on in-situ groundwater level monitoring data. The interpretation of the data consisted in the evaluation of linear regression trends and the ranking of groundwater levels (i.e. the comparison of groundwater levels in 2022 with historical values), based on groundwater level composite hydrographs that were calculated over aquifers or other relevant reporting units (e.g. hydrogeological regions, groundwater bodies). This methodology was piloted in 10 countries, where data from the national groundwater monitoring networks were available, using a period of record of 10 years (2013–2022). A complete description of the methodology can be found in the methodology report[[4]](#footnote-4). The results obtained in the 10 pilot countries illustrated the feasibility of reporting on groundwater levels globally, based on in-situ monitoring data, and will hopefully trigger the participation of WMO Member States and Territories in the next edition of the report. In the meantime, the preliminary results showed some limitations with the methodology, regarding for instance the data selection, the data aggregation over aquifers (or other reporting units) or the type of trend analysis. A description of these limitations can also be found in the methodology report. Over the last months, research has been carried out to consolidate the methodology, during which several options have been tested. On that basis, a proposal for an updated methodology has been developed, which is presented in this report.

# Description of the methodology

## Outline

The main methodological steps are represented in Figure 1. Reporting on groundwater levels is based on in-situ groundwater level monitoring data made available by national or subnational institutions in charge of groundwater monitoring. Time series are assessed by means of trend analysis and ranking, at each monitoring station. The results are subsequently aggregated over spatial units, such as aquifers (if aquifer boundaries are available) or grid cells, for the sake of presenting the results in one world map.

A diagram of a data selection

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Figure 1 Outline of the methodology.

## Data selection

### Period of record

Trend analysis and ranking are commonly assessed over long-term time series equal to or longer than 20 years. For the sake of data availability, it is proposed to work with a period of 20 years. However, many countries do not have 20 years’ time series. In those cases, it is then acceptable to fall back on 10 years’ time series, if available. For instance, if a country started a monitoring network in 2010, it will not be possible to work with a 20 years’ time series, so the last 10 years of record would be used instead. If another country started a monitoring network in 2018, it will not be possible to analyse the data from this country. Results from 10 years’ and 20 years’ periods will be presented on separated maps. Using as many years as available is not considered an option because the results would not be comparable.

### Management of suspicious data and outliers

Unrealistic data were not found to have a significant impact on the results during the preliminary study. Yet, it is proposed to discard data that can be identified as erroneous with automatic logical checks. This could be for instance 0 or –9999 values. A preliminary inspection of each dataset will serve to identify and discard such data input errors. Unless the dataset identifies artesian wells, negative values will be discarded (since groundwater levels will be expressed in (positive) depth below the top of the well, negative values would amount to groundwater levels above the top of the well).

It is a common practice in time series analysis to discard outliers. However, an outlier is not necessarily an erroneous data point. Moreover, setting up rules to discard outliers usually requires a good understanding of the hydrogeological system, which is not available for a global assessment. For these reasons, this methodology does not include a procedure to detect and discard outliers.

### Data completeness

The consistency of groundwater level monitoring data is essential for time series analysis. Time series with as little as one measurement per year will be selected, as long as the measurements have been taken each year at the same period of the year. This is to avoid inconsistent time series comprising measurements taken during different seasons. It is not possible to work with globally-defined seasons, because seasons vary from place to place. Therefore, the methodology is based on calendar months. It works as follow (Figure 2):

1. Unrealistic data are discarded (e.g. -9999, 0 or negative values).
2. A data gap threshold is defined for accepting/rejecting time series with data gaps. Over a period of 20 years, a threshold of 90% would result in the rejection of time series with more than 2 years without data, whereas a threshold of 80% would accept up to 4 years without data. Trials with data from Chile and the Ogallala aquifer (USA) show that there is a very good agreement between time series analysis based on the 80% threshold and the 90% threshold. It is thus appropriate to use a 80% threshold, per default, so as to include a larger number of time series. It remains an option to use a lower threshold for countries where datasets have more data gaps.
3. Data are aggregated into monthly values. If a month contains only one data, this data will be taken as monthly value. If more than one data are available, the average of the data will be used as monthly value. If no data is available, no value will be taken (Nan).
4. Each time series is split into 12 time series, one for each month of the year. The time series of January contains the monthly values from January, the time series of February contains the monthly values from February, and so on...
5. Whether the values of each of the 12 time series can be selected or not will be determined through multiple steps, as explained below. This procedure begins with the time series that has the highest number of values, i.e. the time series that has most chance to be selected. The 12 time series are thus sorted according to the number of values that they contain, in descending order.
6. Following that order, one by one, each of the 12 time series undergoes the following steps (also illustrated with an example in Figure 3):
   1. If there is no missing value (e.g. the time series of January has a value for each January within the period of interest), all values are selected and stored in the final time series of the monitoring station.
   2. If there are missing values, adjacent values are sought to fill in the gaps:
      1. If only one adjacent value is available (i.e. the value from the precedent or successive month), that value is used to fill in the missing data. This value will not be available to complement the next time series in the list.
      2. If values from both the precedent and successive months are available, the mean of these two values is calculated and used. The two adjacent values remain available to complement the next time series in the list.

If the number of values of the time series meets the threshold that has been previously defined, the values are selected. If not, the values are not selected and remain available to complement the next time series in the list.

To summarize, each time series selected for the analysis is made of monthly values, corresponding to single measurements or, if several measurements are available, an average of these measurements. Time series might contain as little as one monthly value per year. The percentage of empty years does not exceed the data gap threshold (i.e. 80% per default).

More information on the data selection, including the algorithm, can also be found in the public GitHub repository (https://github.com/UNIGRAC/Global-Reporting-Groundwater-Levels).

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Figure 2 Flow diagram of the data selection methodology.

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Figure 3 Example of data selection with a dummy time series.

## 2.3 Ranking

The ranking is used in many countries to report on the state of groundwater levels (IGRAC 20202). It is also a key indicator of the WMO Global Hydrological Status and Outlook System (HydroSOS), and it has been used to report on other hydrologic variables covered by the State of Global Water Resources report. Monthly values that have been selected according to the selection procedure explained above are aggregated into yearly averages, then these yearly averages are ranked in ascending order. Based on that classification, the rank of the latest year is determined in terms of percentile, and categorized as follow:

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| “Above normal” | 0.75 < percentile |
| “Normal” | 0.25 < percentile < 0.75 |
| “Below normal” | percentile < 0.25 |

## 2.4. Trend analysis

The Mann-Kendall test is used for analyzing the trend in groundwater level time series, in combination with the Sen slope. While the Mann-Kendall test identifies whether there is a decreasing or an increasing trend, the Sen slope identifies a trend line and its slope. The Mann-Kendall test has been used in many studies and in several national groundwater reporting methodologies. It is deemed more robust than a linear regression (which was used in the previous methodology), in the sense that it identifies a rising or a declining trend only if it is statistically relevant, whereas the linear regression identifies a trend in any case. Auto-correlation tests are performed to identify time series with cyclic patterns, in which case the modified Mann-Kendall test is used instead. Since we are working with time series of monthly values that contain data gaps, the significance level of the Mann-Kendall test is reduced from 95% (standard) to 90%. Otherwise, the test might fail to recognize some valid trends. More information on the trend analysis methodology, including the algorithm, can be found on a public GitHub repository (<https://github.com/UNIGRAC/Global-Reporting-Groundwater-Levels>).

## 2.5 Spatial aggregation

The results of the trend analysis and the ranking is represented with circle symbols, such as on Figure 4, where the colour of the circles indicates whether there is a rising trend, a declining trend, or no trend, and the size of the circles indicates the magnitude of the trend (the same is done for the ranking). The aggregation can take the form of a percentage of monitoring stations with a rising trend, a declining trend, or no trend (or above normal ranks, normal ranks, below normal ranks), which can be symbolized on a map with a mix of three colours. Such aggregation can be done over aquifer units, if such information is available and can be included in the report. The results can also be aggregated over grid cells, for the sake of representing the results on a global map.

A map of a field with red and blue spots

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Figure 4 Ranking of 2020’s groundwater levels in the Ogallala aquifer (USA). Aggregated results can be expressed as a percentage of wells in each ranking category.

1. FAO (2016) Global Diagnostic on Groundwater Governance. FAO, Rome. Available from: http://www.fao.org/3/a-i5706e.pdf [↑](#footnote-ref-1)
2. IGRAC (2020) Groundwater monitoring programmes: A global overview of quantitative groundwater monitoring networks. Available from: https://www.un-igrac.org/resource/national-groundwater-monitoring-programmes-global-overview-quantitative-groundwater [↑](#footnote-ref-2)
3. https://wmo.int/publication-series/state-of-global-water-resources [↑](#footnote-ref-3)
4. https://github.com/UNIGRAC/Global-Reporting-Groundwater-Levels [↑](#footnote-ref-4)