United Nations
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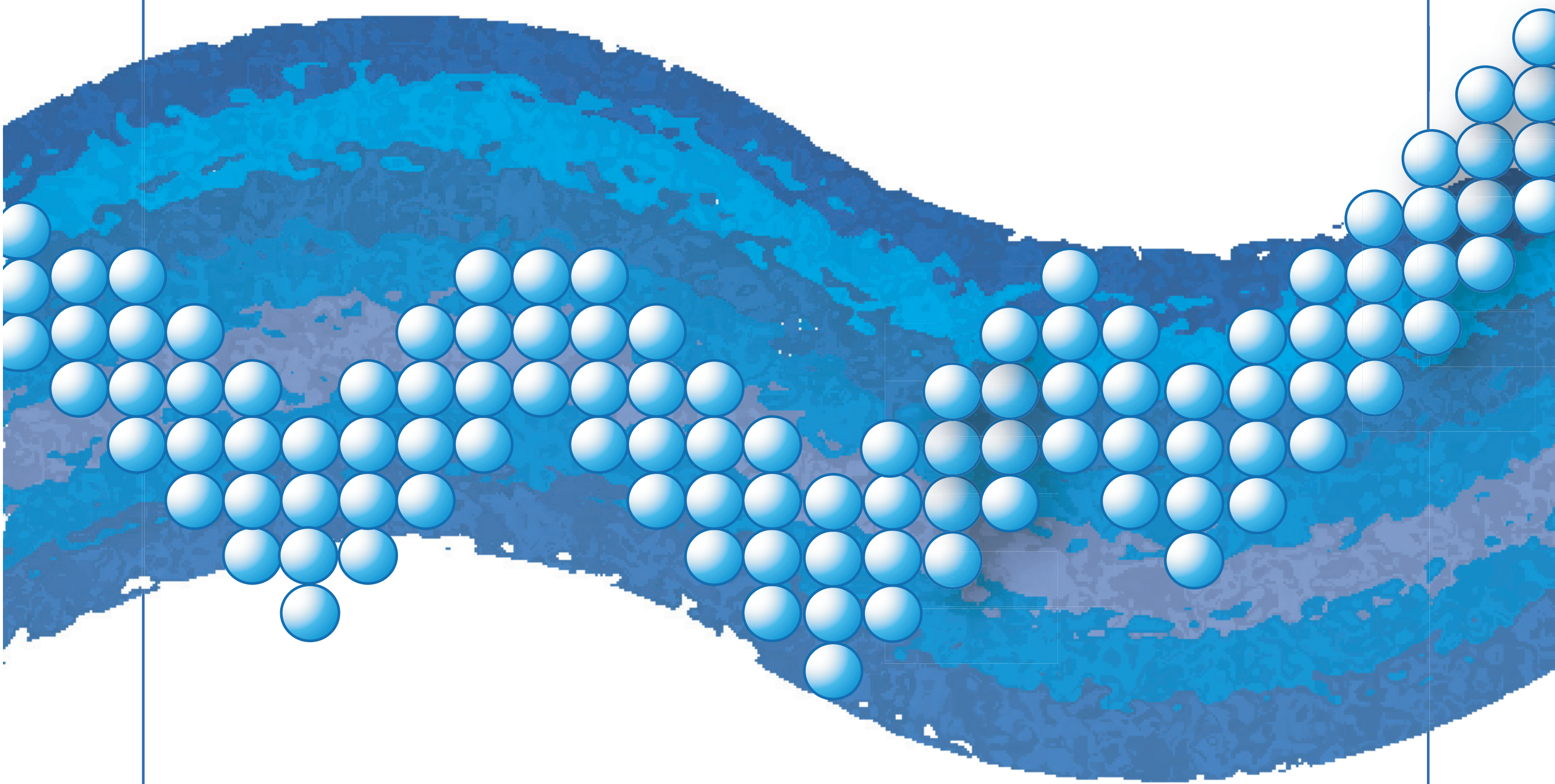
Groundwater resources sustainability indicators



Groundwater Indicators Working Group
UNESCO, IAEA, IAH

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IHP-VI, SERIES ON GROUNDWATER No. 14

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Groundwater Resources Sustainability Indicators

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Preamble

Identification and development of indicators has been recognized as the cornerstone of the UN-World Water Assessment Programme (WWAP). The programme has resolved the significance of indicators in the overall context of assessment of water resources as the most 'vital instruments'. Recognizing the difficulty of indicator development, the First Edition of the World Water Development Report (WWDR)– the principle product of WWAP – has noted that: '*It is essential that both the conceptual framework for indicator development and data gathering be subject to further scrutiny.*' Understandably, much still remains to be done to perfect indicators to be included in the WWDR. However, any focused study and guided effort, such as this activity, with full ownership of member states, UN system agencies, and partner agencies, can prove to be a significant milestone in both methodological advancement and simplification for indicator development.

Development of groundwater indicators has been taken up by UNESCO under the Sixth Phase of the International Hydrological Programme (IHP), Theme 2: Integrated Watershed and Aquifer Dynamics. This effort also draws in the expertise and support of the International Atomic Energy Agency (IAEA) and the International Association of Hydrogeologists (IAH). These organizations together also draw in support of a group of select professionals and have formed a groundwater indicators working group (WG) composed of UNESCO, IAEA and IAH experts. The WG has thoroughly reviewed the issues raised in the first World Water development Report (WWDR) and, at the outset, maintained the need for taking a longer-term horizon for groundwater indicator development. The indicators proposed in this report, although simple, are both scientifically-based and policy-relevant. As agreed during the UN system-wide meetings on indicator development at FAO-Rome (2002) and UNESCO-Paris (2004) and groundwater indicator WG meetings at Paris-UNESCO (2002), Vienna-IAEA (2003), Paris-UNESCO (2004) and Utrecht-IGRAC (2004), a balanced scientific and policy-based approach has been employed in deriving groundwater indicators.

Attempts to develop water related indicators are not new. Since early 1960s, efforts have been underway to develop a meaningful set of indicators and indices for water resources. The early efforts of UNESCO's International Hydrological Decade, subsequent International Hydrology Programme (IHP) phases, FAO, IAEA and UNEP as well as professional organizations have produced several important methodological guidelines toward indicator development. Against this background, the WWAP has been mandated to select indicators and adopt a methodology for further developing indicators by learning from previous initiatives. In the course of these efforts, WWAP has learned that this is a long-term process where each previous milestone provides the direction – or directions – to get to the next one. Amidst such complexity and tradeoffs, WWAP agreed on a methodological approach, identified some indicators, carried out limited testing and developed a better understanding and appreciation of the problems of indicator development.

Collectively, the UN agencies have resolved that a longer-term horizon for indicator development is needed. It is concluded not to reinvent wheels, but to make use of the many ongoing indicator development initiatives. The agencies explicitly decided to use existing indicators and actively investigate whether these indicators meet the criteria instead of developing new indicators. Finally it has been concluded to develop or adopt a limited set of quality indicators with excellent data backup rather than to pursue a large number of lesser quality indicators. The same strategy has been applied to the development of the groundwater indicators.

This effort has generated enough evidence that data availability for UN programmes, such as WWAP and IHP, is contingent upon the member state's willingness to contribute data and the sensitivities of the bilateral/multilateral agreements which are already in place. As noted by Maurer (2003), the former can be a tricky issue as the data sourced by the UN agencies hardly contributes to improve and/or enhance water resource management capability of the countries. Similarly, in the latter, as noted by Shah and Aryal (2003), confidentiality and 'defense' like treatment of water-related data can seriously affect good indicator development for comparative purposes. The dependence of indicator development on data can lead to the situation in which data availability drives the selection of indicators, which, in turn, reinforces the collection of the same data. The expert group on groundwater indicator development has noted this problem and the proposed indicators have been considered in this context.

The set of groundwater indicators presented in this report is a short-list derived from over one hundred conceptual water related indicators. These have been short-listed based on some of the problems and caveats as noted above. It is expected that the third edition of the WWDR will fully utilize the set of groundwater indicators for comparing and contrasting the groundwater situation around the world.

Acknowledgements

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The following experts contributed to this work as members of the UNESCO-IAEA-IAH joint Working Group on Groundwater Resources Sustainability Indicators: Jan Girman (DWAF), Naim Haie (University of Minho), Ricardo Hirata (IAH), Annukka Lipponen (UNESCO), Elena Lopez-Gun (LSE), Bhanu Neupane (UNESCO), Tushaar Shah (IWMI), Jac van der Gun (IGRAC), Bill Wallin (IAEA), and Jaroslav Vrba (IAH). The work of the group was coordinated by Jaroslav Vrba (IAH). Geo Arnold (RIZA), Yongxin Xu (University of Western Cape), Jean Margat and Anna Belousova (IAHS) also contributed to the effort in the early stages of the group's work.

Thanks are expressed to John Clinton from British Geological Survey, for scientific review and linguistic layout of the manuscript.

Contents

7 Case studies

The proposed groundwater indicators have been implemented in several case studies at the aquifer scale (Spain) and state and national level (The Republic of South Africa, Finland and the State of São Paulo – Brazil). The method of formulation of individual indicators is presented in the example of the indicator for renewable groundwater resources per capita.

7.1 Method of calculation of the Renewable Groundwater Resources per Capita Indicator

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7.1.1 DEFINITIONS

➔ **Groundwater resource: Gwr**

Groundwater resource means the total renewable groundwater resources without taking into account its quality, but brackish and saline water are excluded. Groundwater reserves (storage) are also not included.

➔ **Internal: Int**

The total renewable groundwater resource generated from endogenous precipitation (the only part that can be summed up for regional analysis).

➔ **Inflow (an external flow): Inf**

The total renewable groundwater resource that enters a country's aquifer systems from the upstream country's aquifers (naturally or through agreements).

➔ **Outflow (an external flow): Out**

The total renewable groundwater resource that leaves a country's aquifer systems to the downstream countries' aquifers. Groundwater outflow into the oceans is of special importance for coastal regions (control of saltwater intrusion) and should be included in the estimation in such regions.

➔ **Natural: Nat**

The potential (theoretical) total renewable groundwater resource of a country generated through precipitation in its natural condition, excluding all human influences (both Internal and Inflow). Its long term yearly average value is 'assumed' to be stable in time.

Note: its minimum value 'in the lowest flow period of the lowest flow year' is also important.

➔ **Actual: Act**

The natural total renewable groundwater resource of a country subtracting a portion of its Natural Inflow (geopolitical, socio-economical and environmental constraints):

A. withdrawn by an upstream country and/or

B. preserved to be delivered to a downstream country through agreements.

This is an amount that varies with time.

➔ **Exploitable: Exp**

Not all of the actual renewable groundwater resource of a country is usable for development purposes. There are important restrictions such as: environmental and economic feasibility of abstracting groundwater; the physical possibility of utilising the groundwater which naturally flows out to the sea; groundwater quality; etc.

Note: other terms which are used in this context are: usable groundwater reserves, developed groundwater resources, safe yield of aquifer, etc.

➔ **Seepage: See**

Surface water resource which infiltrates to become part of the groundwater resource.

➔ **Baseflow: Bas**

Groundwater resource which becomes part of the surface water resource (streamflow is important for aquatic habitat).

➔ **Dependency ratio: Dr**

Percentage of the total renewable water resource originating outside the country.

➔ **Inhabitants: Inh**

The demographic variables that have implications for ecological systems include population size and rate of change over time (birth and death rates), age and gender structure of a population, household distribution by size and composition, spatial distribution (urban versus rural and by country and ecosystem), migration patterns, and level of educational attainment. The interactions between population and ecosystems are complex.

Population size and other demographic variables influence the use of food, fiber, clean water, energy, shelter, transport, and a wide range of ecosystem services.

Increases in population decrease the per capita availability of both renewable and nonrenewable resources. When coupled with growing income and other factors such as urbanization and market development, population growth increases the demand for food and energy.
Demographic projections suggest that future population growth rates will not be uniform throughout the world. At least 95 percent of the additional 3 billion or so people likely to inhabit the planet in the next 50 years will live in developing countries, and most will be in the tropics and sub-tropics (World Resources Institute, 2003).

Artificial recharge should be added where it is a significant factor. Depending on the source of this water, care should be taken that there is no double accounting related to this component.

7.1.2 METHODOLOGY

	Natural, Nat	Actual, Act
Internal, Int	IntNat	IntAct = IntNat
Inflow, Inf	InfNat	InfAct
Outflow, Out	OutNat	OutAct
Total	GwrNat = Gwr	GwrAct

The units of all the variables are the same, e.g., m^3 (per year).
IntAct = IntNat according to our definitions.

Data on Inflows and Outflows are rarely available and difficult to gather, needing a good understanding of the aquifer (FAO, 2003). In the best scenario, it would be desirable that a country agrees with its upstream neighbours to produce one set of data (say only the Inflows). Then Inflow of one country is (a portion of) the Outflow of the other. But it should be also mentioned that it has been noticed that with negligible recharge in an upstream country, there are still Outflows from that country meaning that groundwater flows whether there is recharge or not (renewable or not). Outflow into sinks (such as oceans and seas) are not considered here.

$$\text{IntNat} = \text{Rec} + \text{See} - \text{Bas}$$

Rec = Total groundwater recharge generated from precipitation within a country.

Care should be taken that the amount (See – Bas) is not duplicated in the estimation of surface water resources.

$$Gwr = IntNat + InfNat = Rec + See - Bas + InfNat$$

$$GwrAct = IntAct + InfAct - OutAct = IntNat + InfAct - OutAct$$

$$GwrInh = Gwr/Inh \; [m^3/year/inh]$$

$$GwrDr = 100 \times InfNat / Gwr$$

Trend analysis

Descriptive trend analysis:
How is the state of the indicator and/or part of the indicator developing?

Examples in our case:
- Groundwater resource trends over time because of climate change.
- Population trends over time.
- And how the indicator might change by combining the above 2 points?

7.1.3 CALCULATION METHODS

Recharge (Rec)

Refer to the methods described under the indicator: Groundwater recharge/Total abstraction of groundwater. Some examples:

A) Kinzelbach (2002) gives a number of methods for calculating groundwater recharge in arid and semi-arid regions:

➔ Direct measurements:
- Lysimeters;

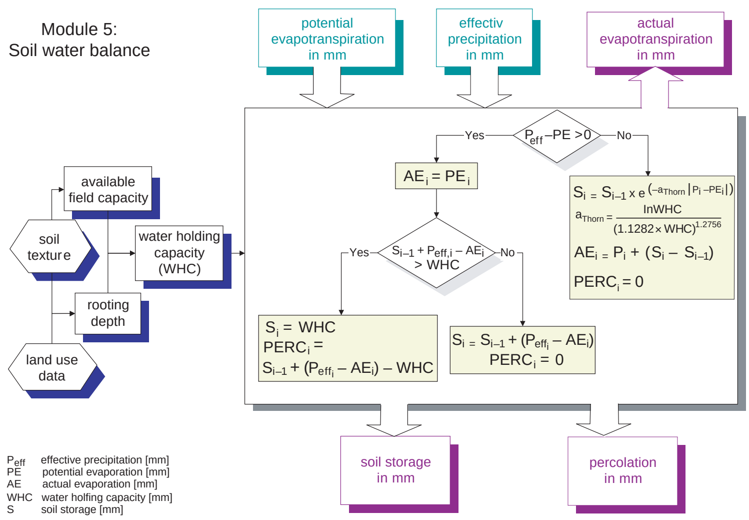
➔ Water balance methods (including hydrograph methods):
- Water table rise method – particularly if in-outflows are known or are negligible;

➔ Darcyan methods:
- Numerical flow model;

➔ Tracer methods:
- Chloride method.

B) Rutledge (2000) from the USGS-RORA programme uses streamflow records to estimate groundwater recharge.

C) Ulmen (2000) uses a Soil Water Balance to find Rec:

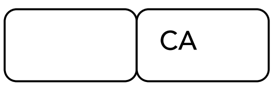


Source: Ulmen (2000).

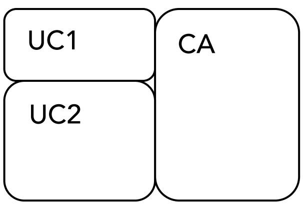
InfNat

This quantity for a country depends on the situation of its upstream countries. Hypothetical examples:

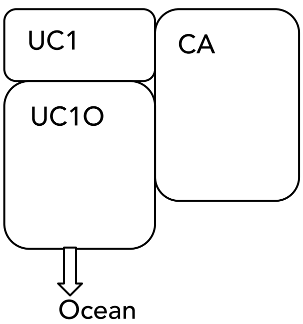
Country being analysed = CA
Upstream Country i = UCi, I = 1, 2, …
Upstream Country i with Ocean/Sea = UCiO



InfNat into CA = Gwr of UC1



InfNat into CA = a x Gwr of UC1 + Gwr of UC2 (a < 1, in this case UC1 being upstream to both CA and UC2, we have a = 1/3 in proportion to the perimeter of their common border)



InfNat into CA = a x Gwr of UC1 + b x Gwr of UC1O
(a = 1/3, b = 1/4)

InfAct and OutAct

To calculate these quantities, withdrawals and treaties of each country in relation to its neighbouring countries need to be known.

Inh

UN Population Division; UNFPA; FAOSTAT; US Census Bureau; etc.

See – Bas

A- See

A1-

River channel water balance

If recharge is confined to seepage from a river channel, the observations necessary could in principle be very simple. If flow is measured between two points along the river, the difference may at least convey some information about an upper bound for seepage.

A2-

Semi-arid areas:

The groundwater resources could be obtained from (FAO, 2003):

- rainfall infiltration estimates or
- analyses of measured groundwater levels/heads in aquifers.

A3-

Telis (2001) gives estimation of infiltration rates of saturated soils in a river basin in the US.

B- Bas

Particularly in **humid areas**, river baseflow is presumed to be purely groundwater outflow. In the long term, this outflow must balance the inflow, i.e., recharge, hence the importance of calculating baseflow. However care should be taken for the calculation of the surface flow as it includes a part of the groundwater resources.

B1-

(Ulmen, 2000)

$$Bas_{i,j} = k \times Bas_{i,j-1} + (1-k) \times Rec_i / d_i \qquad \forall_j = 1, d_i$$

where

k daily recession constant [dimensionless]

$Bas_{i,j}$ baseflow at the j-th day (of the i-th month) [mm]

Rec_i recharge (percolation) in the i-th month [mm]

d_i number of days of the i-th month

Baseflow of the i-th month Bas_i is finally equal to the sum of all daily base flows $Bas_{i,j}$ of that month:

$$Bas_i = \sum_{j=1}^{d_i} Bas_{i,j}$$

Please refer to the reference for information about k and how to find it. Two methods for its calculation are given:

- from measured daily runoff (gauged basins),
- hydrogeology (where daily runoff is not available – ungauged basins).

Thornthwaite and Mather (1957) use k = 0,5 invariant with time and space:

$$Bas_i = 0.5 \times Bas_{i-1} + 0.5 \times Rec$$

B2-

Sloto and Crouse (1996) uses three methods of hydrograph separation (in HYSEP; USGS) to separate a streamflow hydrograph into base-flow and surface-runoff components.

C- See – Bas

For the case of Tunisia (FAO, 2003), the overlap between surface and groundwater = less than 50% of groundwater recharge; only a small part of the groundwater is drained by rivers (equal to the low flow of water courses). Most of the groundwater escapes and flow out into the sea, or into sebhat in arid areas. In addition, there is probably some infiltration from surface water.

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