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INTRODUCTION

Development of water related indicators has been taken up under the Sixth Phase of the International Hydrological Programme. The UNESCO/IAEA/ IAH Working Group has been charged with the development of groundwater resources sustainability indicators that can be applied at the global, national and aquifer level. The following experts, mostly IAH members, joint working group: Jan Girman, Naim Haie, Ricardo Hirata, Annuka Lipponen, Elena Lopez-Gun, Bill Wallin, and Jaroslav Vrba The work has been coordinated by Jaroslav Vrba. The indicators proposed, methodology of their development, the social and economic aspects of groundwater indicators, relevant case studies and indicators sheets were published in UNESCO IHP Series (Vrba and Lipponen ed., 2007).

The main function of indicators is simplification, quantification, communication, ordering and allowing for comparison of different countries and regions . Indicators provide condensate information on the system or process under consideration in an understandable format. They therefore act as important communication tool for policy makers, managers and the public.

The most common use of groundwater indicators is describing the current status of the resource. Regular measurements of indicators provide time series that may inform on the functions of the system or its response to stress. An indicator value can also be compared to a reference conditions and so it can be used as a tool for assessment. Finally groundwater indicators can be used for predicting the future. When models are linked to specific indicators, a time series can be extended into estimated scenarios.

Development of groundwater indicators is a scientific approximation process of presentation of groundwater and aquifer characteristics to various target groups in simplified and understandable form, However, groundwater data scarcity and incompatibility is a serious limitation in formulation of scientific sound and policy relevant indicators. Developing 'good' indicator requires statistically meaningful time series of reliable data to meet defined criteria. If data can be gathered according to commonly agreed standardization measures, than lessons can be drown that may be transposable from one case to the other. However, scaling has to be considered as an important attribute in indicator implementation.

Groundwater indicators serve a variety of management and policy goals. They help in the improvement of groundwater resources planning and management through better assessment of the groundwater resource situation in a given hydrogeological unit, through identification of critical problems and their causes and by providing a basis for comparison with similar spatial unit elsewhere.

THE DPSIR FRAMEWORK

The DPSIR framework has been employed in finalizing the set of groundwater indicators. The DPSIR methodology (D-Driving forces, P-Pressures, S-States, I-Impacts, R-Responses) ensures establishment of the relationship between policy and economic issues and the most burning issues in groundwater resources development and management (Fig. 1).

The DPSIR structure is nor a goal in itself but provides a means to coordinate over the challenges area and supports further cooperation between agencies in sharing knowledge and information. Furthermore, the methodology provides an basis for harmonization in terminology and indicators. The same approach has also been adopted as the framework for the development of groundwater indicators.

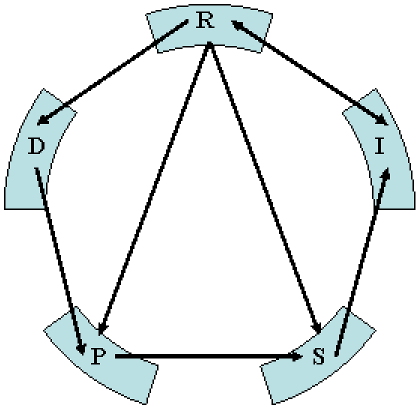

Figure 1. General structure of the DPSIR framework (EEA, 2003).

PROPOSED GROUNDWATER INDICATORS

In the proposed list of groundwater indicators, each of them describes a specific aspect of the groundwater system and/or process and is based on the aggregation of selected variables both quantitative and qualitative. Indicators can be combined into an index, which provides compact and targeted information for groundwater planning, policy and management. The index is dimensionless and weighting and rating systems are applied in its construction.

Proposed groundwater indicators are both scientifically-based and policy relevant, based on measurable and observable data and provide information about groundwater quantity, quality and vulnerability. They are focused on social, economic and environmental aspects of groundwater resources policy and management.

The following groundwater indicators have been developed and tested at the aquifer, national and global scale level:

Renewable groundwater resources (m^3 /year) per capita at aquifer or country level. This indicator defined (estimated) as the total annual renewable groundwater resources is based on groundwater recharge generated from precipitation, the total volume of actual groundwater flow within aquifers coming from and living to the neighbouring countries, seepage from surface water to groundwater and discharge of groundwater to surface water bodies. This is a driving force indicator of social and economic relevance and of great importance for planners and policy makers.

Total groundwater abstraction/Groundwater recharge (m^3) indicator. Total groundwater abstraction means total withdrawal of water from a given aquifer for the water supplies, agriculture and other purposes. Various methods of groundwater recharge have been analysed with respect to climatic, topographic and hydrogeological conditions and effects of land use, vegetation cover and soil type.

Total groundwater abstraction (m^3)/Exploitable groundwater resources (m^3) indicator. The term 'exploitable groundwater resources' means the amount of groundwater that can be abstracted from a given aquifer under existing hydrogeological and ecological conditions, current social and economic constraints and political priorities.

Groundwater as a percentage of total use of drinking water on country level indicator is of social importance since indicates population dependency on groundwater.

Total exploitable groundwater non-renewable groundwater resources (m^3)/annual abstraction of non-renewable groundwater resources (m^3/year) indicator. The annual abstraction should be calculated as a mean value over a significant range of years. An estimate of total lifetime of non-renewable aquifer can be made from current abstraction figures , but must taken in consideration future sustainable development plans for groundwater resource conservation for future generations.

Groundwater depletion indicator expresses excessive groundwater withdrawal from the aquifer which may be reflected in continuous, long term and areal extent of groundwater level decline, drastic reduction or even loss of base flow, changes in groundwater quality and age, land subsidence and in coastal aquifers in increasing groundwater salinity. Increase of pumping costs and decrease of well production jeopardize the economic and social activities sustained by aquifer.

Groundwater quality indicator informs about the present status and trends in groundwater quality and helps to analyse groundwater quality problems in space and time. Indicator is based on groundwater chemical analysis and its comparison with drinking, irrigation or other standards. Availability of data on drinking water standards level is often restricted, indicator can by therefore formulated on widely measured variables electric conductivity, chloride and nitrate, which indicate present status as well as changes in groundwater quality.

Groundwater vulnerability indicator. Natural vulnerability of groundwater is considered for indicator formulation , based solely on hydrogeological factors and defined as an intrinsic property of a groundwater system that depends on the sensitivity of that system to human and/or natural impacts. Parameters of DRASTIC index are applied for groundwater vulnerability assessment.

Groundwater treatment requirements indicator. The classification divides the indicator in three categories according to how extensive a treatment of groundwater is needed: 1) suitable for specific use without treatment (appropriate quality), 2) simple treatment needed (e.g. dilution, filtration, desinfection), 3) technological demanding treatment methods needed(e.g. membrane methods, reverse osmosis, flocculation).

SOURCES OF GROUNDWATER DATA FOR INDICATORS FORMULATION

Formulation o groundwater indicators is affected by uncertainty , which is inherent in several methods of indicators formulation. Uncertainties arise particularly from data scarcity and limitations in knowledge of many aquifers and groundwater basins. In many countries and for many aquifers the necessary groundwater datasets are not yet available.

Establishment and/or improvement and operation of monitoring networks and programmes and real-time data gathering are the main sources of groundwater data for formulation of indicators. Long time series of groundwater data will be a vehicle for better understanding of groundwater system, more accurate and science based groundwater resources evaluation and groundwater indicators formulation. However, in many countries owing to financial and logistic problems systematic groundwater monitoring activities and spatial and temporal coverage of groundwater monitoring variables are decreasing

Various satellite based programmes provide consistent, spatially and temporally coherent data at the global and regional scale and political boundary free view of major elements defining the water cycle. With respect to groundwater the most promising is GRACE (Gravity Recovery and Climate Experiment) mission implemented in several studies focused on identification and assessment of variations in groundwater level and groundwater storage. Space based measurements do not provide accurate data (inclusive of promising gravimetric and radar altimetry remote sensing) and have to be therefore integrated with terrestrial measurements and calibrated according to data acquired from in-situ observations in monitoring wells.

Air born measurements in combination with geophysical photographic and geobotanical methods produced data which may be useful for formulation of groundwater depletion and pollution indicators.

In-situ measured groundwater data is useful for calibration of conceptual and mathematical models of groundwater system. Mathematical models provide reliable predictions of the groundwater system's behaviour and support indicators implementation on spatial (aquifer) scale. The implementation of statistical methods, particularly factor and cluster analysis , can provide reliable data needed for groundwater modelling as well as groundwater indicators formulation.

INDICATORS SHEET

Groundwater indicators profiles are presented on the indicators sheets developed in the framework of the Word Water Assessment Programme for all types of indicators. Standardized indicators sheets facilitate mutual comparability of indicators characteristics, particularly their position in the DPSIR framework, methods of indicator computation, units of measurements, scale of application, interpretation, linkages with other indicators and references.

CONCLUSIONS

The proposed set of groundwater indicators is based on observable data and provide information about 1) groundwater quantity, quality, and vulnerability, 2) human and ecological dependency on groundwater, and 3) human and natural stresses on groundwater and aquifers. The development of more sophisticated indicators depends on international and countries capabilities to cope with challenges related to data monitoring, collecting, assessment , management and reporting both on national and international level.

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