TWAP
TRANSBOUNDARY WATERS ASSESSMENT PROGRAMME

Transbounday Aquifers and Groundwater Systems of Small Island Developing States

Status and Trends

VOLUME 1: GROUNDWATER

UNEP
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UNESCO
United Nations
Educational, Scientific and
Cultural Organization
International
Hydrological
Programme

Published by the United Nations Environment Programme (UNEP), JANUARY 2016

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ISBN: 978-92-807-3531-4

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Citation

This document may be cited as:
UNESCO-IHP and UNEP (2016). Transboundary Aquifers and Groundwater Systems of Small Island Developing States: Status and Trends UNEP, Nairobi.

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VOLUME 1 AQUIFERS

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United Nations
Educational, Scientific and
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International Groundwater Resources Assessment Centre

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Acknowledgments

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Reviewers

The authors are grateful to the following reviewers:

Name	Primary affiliation	Primary review responsibility (chapter)
TWAP Scientific and Technical Advisory Committee (STAC)		
Prof. Dr. Wilhelm Struckmeier	Institute for Environmental Systems Research in Osnabrück, Germany	Whole report (interim and final draft)
Dr. Pierre-Philippe Mathieu	European Space Agency (ESA), European Space Research Institute (ESRIN)	Data Portal and Website
Dr. Ashbindu Singh	Environmental Pulse Institute	Data Portal and Website
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Birguy Lamizana	UNEP, DEPI	Whole report
Evelyn Ongige	UNEP, DEWA	Whole report (Gender)
Mick Wilson	UNEP, Chief Scientist's Office	Whole report

The authors are also grateful to the following for comments provided at various stages of the assessment and support for the review and preparation of this report:

- The National Experts (list included in on-line annexes) and participants to the regional workshops.
- The UNESCO ISARM networks, and especially the UNESCO/OAS ISARM Americas Programme.
- The UNESCO-IHP National Committees.
- The TWAP Groundwater Regional Coordinators (Yusuf Al Mooji, Deborah Bushel, Lucila Candela, Greg Christelis, Cheikh Becaye Gaye, Alberto Manganelli, Dimitri Plaksin, Peter Sinclair, Omar Salem, Sangam Shrestha, Pieter Van Don Gen and Sahara and Sahel Observatory-OSS).
- Eberhard Braune, University of the Western Cape.
- The regional organisations (in particular UNESCWA, OAS, OSS, SPC), institutes, and other independent experts.
- Emilie Chaillan, Nienke Ansems and Friedemann Scheibler, UNESCO Centre IGRAC.
- Holger Treidel, Ivica Trumbic, Leszek Bialy, Matthew Lagod, Giorgio Faedo, Marina Rubio and Chloé Meyer, UNESCO-IHP.

Copy Editor

Peter Saunders

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Design and Layout

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Administrative Boundaries

Source of administrative boundaries used throughout the assessment: The Global Administrative Unit Layers (GAUL) dataset, implemented by FAO within the CountrySTAT and Agricultural Market Information System (AMIS) projects.

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Preface

The Global Environment Facility (GEF) approved a Full Size Project (FSP), "A Transboundary Waters Assessment Programme: Aquifers, Lake/Reservoir Basins, River Basins, Large Marine Ecosystems, and Open Ocean to catalyze sound environmental management", in December 2012, following the completion of the Medium Size Project (MSP) "Development of the Methodology and Arrangements for the GEF Transboundary Waters Assessment Programme" in 2011. The TWAP FSP started in 2013, focusing on two major objectives: (1) to carry out the first global-scale assessment of transboundary water systems that will assist the GEF and other international organizations to improve the setting of priorities for funding; and (2) to formalise the partnership with key institutions to ensure that transboundary considerations are incorporated in regular assessment programmes to provide continuing insights on the status and trends of transboundary water systems.

The TWAP FSP was implemented by UNEP as Implementing Agency, UNEP's Division of Early Warning and Assessment (DEWA) as Executing Agency, and the following lead agencies for each of the water system categories: the International

Hydrological Programme (IHP) of the United Nations Educational, Scientific and Cultural Organization (UNESCO) for transboundary aquifers including groundwater systems in small island developing states (SIDS); the International Lake Environment Committee Foundation (ILEC) for lake and reservoir basins; the UNEP-DHI Partnership – Centre on Water and Environment (UNEP-DHI) for river basins; and the Intergovernmental Oceanographic Commission (IOC) of UNESCO for large marine ecosystems (LMEs) and the open ocean.

The five water-category specific assessments cover 199 transboundary aquifers and groundwater systems in 42 small island developing states, 206 transboundary lakes and reservoirs, 286 transboundary river basins; 66 large marine ecosystems; and the open ocean, a total of 758 international water systems. The assessment results are organized into five technical reports and a sixth volume that provides a cross-category analysis of status and trends:

- Volume 1 – ***Transboundary Aquifers and Groundwater Systems of Small Island Developing States: Status and Trends***
- Volume 2 – Transboundary Lakes and Reservoirs: Status and Trends
- Volume 3 – Transboundary River Basins: Status and Trends
- Volume 4 – Large Marine Ecosystems: Status and Trends
- Volume 5 – The Open Ocean: Status and Trends
- Volume 6 – Transboundary Water Systems: Crosscutting Status and Trends

A Summary for Policy Makers accompanies each volume.

This document – Volume 1 – presents the first comprehensive indicator-based global assessment of status and trends in 199 transboundary aquifers and 42 groundwater systems of Small Island Developing States. It was prepared by UNESCO-IHP and UNESCO International Groundwater Assessment Center (IGRAC) in partnership with the Simon Fraser University (Canada) and Frankfurt Goethe University (Germany).

Acronyms

AET	Actual Evapotranspiration and Recharge
AIMS	Africa, Indian Ocean, Mediterranean and South China Sea
BGR	Bundesanstalt für Geowissenschaften und Rohstoffe
CIESIN	Center for International Earth Science Information Network
EU	European Union
FAO	Food and Agriculture Organization
FSP	Full Size Project
GCM	Global Climate Models
GEF IW	Global Environmental Facility International Waters
GEF	Global Environmental Facility
GGIS	Global Groundwater Information System
IFI	International Financial Institutions
IGRAC	Internationally Groundwater Resources Assessment Centre
IMS	Information Management System
ISARM	Internationally Shared Aquifer Resources Management
MSP	Medium Size Project
ODA	Official development assistance
OSS	Sahara and Sahel Observatory
SDC	Swiss Agency for Development and Cooperation
SFU	Simon Fraser University
SIDS	Small Islands Development States
STAP	Scientific and Technical Advisor Panel
TBA	Transboundary Aquifer
TBA-CU	Transboundary Aquifer Country Unit
TWAP	Transboundary Waters Assessment Programme
UF	Frankfurt University
UNDESA	United Nations Department of Economic and Social Affairs
UNEP	United Nations Environment Programme

UNESCO IHP	United Nations Educational, Scientific and Cultural Organization International Hydrological Programme
UNESCWA	United Nations Economic and Social Commission for Western Asia
UNGA	United Nations General Assembly
UNWWAP	United Nations World Water Assessment Programme
WaterGAP	Water - Global Assessment and Prognosis global freshwater model
WFD	Watch Forcing Data
WGHM	WaterGAP Hydrology Model
WHYMAP	Worldwide Hydrological Mapping and Assessment Programme
WMS	Web Map Service

Technical Summary

Groundwater is an integral part of the water cycle, inextricably linked to surface waters and ecosystems. It is ubiquitous and represents 99 per cent of all liquid freshwater on Earth. It is being exploited aggressively in many regions of the world, and in a number of cases represents the only water available for human uses. A tremendous increase in the utilization of groundwater has occurred in the past few decades thanks to the availability of new and cheaper drilling and pumping technologies. Hydrogeologists refer to this drastic change in groundwater utilization as 'the silent revolution', since it has occurred in many countries in an unplanned and totally uncontrolled way. It went almost unnoticed.

People's initial attitude of taking groundwater, a fundamental natural resource and vital component of our environment, for granted and simply exploiting it according to individual demands has prevailed in most countries of the world until recently, when demographic pressures, economic and technological development, growing climatic variability and other factors have triggered unprecedented changes in the state of our groundwater systems, which have resulted in a growing awareness of the finiteness and vulnerability of this critical resource. We have now come to realize that, without proper knowledge and management, this huge resource can be rapidly and irreversibly degraded. Pollution of aquifers is hardly ever reversible: over-exploitation may have permanent impacts on aquifer resilience and behaviour. We have also realized that many land and water ecosystems depend on groundwater regimes, as is the case for most semi-arid alluvial plains, wetlands, coastal habitats, and even coastal marine environments. Groundwater cuts across basins and landscapes, sustains ecosystems and biodiversity, mitigates the impacts of climatic fluctuations, and contributes to human health and social-economic development. It is now apparent that groundwater, from the shallowest unconfined aquifers to the deepest hidden reserves, has a critical role to play in addressing the new challenges of adapting to the realities of a changing climate and combating desertification.

While groundwater is an inseparable part of overall water resource management, it deserves special attention because of its hidden, invisible nature, and its high stock-to-flow ratio. The common pool resource characteristics of groundwater, the close interaction between groundwater and land use and the often limited understanding among policy makers of its characteristics and of the geological processes that control its behaviour, are additional challenging features. In spite of the efforts being made across the planet to introduce some degree of management to the use of this invaluable resource, groundwater remains largely unknown, and, with some notable exceptions, its exploitation at the global level is far from sustainable. Groundwater resources are rapidly being degraded in terms of quality and quantity, and the opportunities that currently exist for the strategic expansion of groundwater use are being compromised, or simply remain unknown to stakeholders and resource administrators.

In response to this new awareness, the need for groundwater resource assessment and management has come to the forefront of the global agenda on sustainable development. Modern, comprehensive assessments of the groundwater resources available in a given territory are indispensable tools for monitoring, protecting and managing sustainably, and to their full extent, these strategic yet invisible resources, which reside in the subsurface, from shallow near-surface levels down to depths of thousands of metres.

Assessing groundwater means identifying the aquifers systems present in the subsurface at different depths and reaching an adequate understanding of their characteristics and functioning. Eventually, it means understanding the subsurface and its resources.

Deep aquifers are still largely unknown, and so far are only sparsely tapped around the world for abstracting freshwater. Having no or only little recharge, they offer mainly non-renewable resources. However they present opportunities for more intensive exploitation, in particular as an emergency resource and as a buffer for mitigating climate change impacts.

The Global Environment Facility, recognizing that "Groundwater exemplifies, possibly better than any other element of the natural environment, the concept of interlinkages which GEF is striving to translate into operational guidelines for addressing desertification, climate change adaptation and the protection of groundwater dependent ecosystems, such as wetlands." GEF Scientific and technical Advisory Panel, STAP, has, through its International Waters focal area strategies, fostered cooperation among countries that share aquifers in the assessment and joint management of this critical resource.

The Transboundary Waters Assessment Programme, with its ground-breaking Transboundary Aquifers Component, represents a major effort to raise awareness of policy makers, Official Development Assistance (ODA) providers and International Financial Institutions (IFIs), and the scientific community, of the existence, global distribution, main characteristics, current state and likely future trends of all known major transboundary aquifers (>5 000km^2), where a large part of the world's groundwater resources is stored, and where management complexity is compounded by the multi-country shared nature of the resource.

The overall goals of the Groundwater Component of TWAP are to:

(1) Provide a description of the present conditions of transboundary aquifers (TBA) with areal extent >5 000 km^2, and aquifers in Small Island Developing States (SIDS) that will enable the GEF International Waters (IW) Focal Area to determine priority aquifers/regions for resources allocation;

(2) Bring to the global attention the major issues, concerns and hotspots of these transboundary aquifer systems and SIDS aquifers, and catalyse action.

The results of the TWAP Groundwater assessment provide elements to help the GEF and other interested parties to find answers to questions like

(i) What human and ecosystem uses of the water resources are currently affected or impaired (use conflicts, depletion, and degradation)?

(ii) How will water conditions and uses develop during the coming decades? Global change is projected to produce increased pressures during the coming decades, such as higher water demands for food security/irrigation and domestic use, more intensive use of fertilizers and nitrogen, and increasing seawater intrusion in coastal zones.

(iii) Where will these problems occur? Increasing droughts or floods are observed in some areas and have been projected as a result of modelling ¬– these projections need to be incorporated and summarized in the assessment.

(iv) Which international groundwater systems are likely to be able to prevent, buffer or mitigate water-related problems under increasing stresses during the coming decades?

The TWAP Assessment was originally conceived to be carried out at two levels:

Level 1 includes a baseline global assessment and provides for periodic follow-up monitoring of trends and impacts achieved from GEF and other interventions, applying simple and feasible[1] indicators. It also includes a tentative projection of key conditions and concerns over the next few decades.

Level 2 activities consist of a more detailed assessment of a few selected pilot systems, as an example of the level of aquifer knowledge necessary for management purposes.

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[1] Feasible means that the data required to calculate the indicators are either readily available or can be collected in the framework of the GEF TWAP Full Size Project.

Because of resource constraints, GEF decided to limit the scope of the TWAP full-sized project to Level 1 only. The Level 2 assessment is currently being carried out by UNESCO International Hydrological Programme (IHP) with the financial assistance of the Swiss Agency for Development and Cooperation (SDC) in three transboundary aquifers: The Pretashkent (Central Asia), the Stampriet (Southern Africa) and the Trifinio (Central America).

The main products of TWAP Groundwater can be found in the websites presented in Table 1.

Table 1.1. Products of TWAP Groundwater component

Outputs	Coordinates
Transboundary Aquifers Assessment Methodology (2012)	www.twap.isarm.org
Questionnaire Template	www.twap.isarm.org
Template for Transboundary Aquifer Information Sheets	www.twap.isarm.org
WaterGAP - Global-scale modelling and quantification of indicators for assessing transboundary aquifers – Final Report	www.twap.isarm.org
Assessment of SIDS Groundwater Systems - Final Report	www.twap.isarm.org
Transboundary Aquifer Information sheets (197)	http://twapviewer.un-igrac.org
SIDS Hydrogeological Profiles	http://twapviewer.un-igrac.org
SIDS Variables Values; SIDS references	www.twap.isarm.org
TWAP Groundwater Information Management System	http://twapviewer.un-igrac.org
Transboundary Aquifers and Groundwater Systems of Small Island Developing States: Status and Trends – Final Report	www.twap.isarm.org

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1. Global assessment of transboundary aquifers

Data Sources

Data for the assessment of transboundary aquifers come from two different sources:

Global Inventory

This involved acquisition of data using networks of more than 200 national experts. Questionnaires were used to collect data and information in a structured way. The data collected include mapping of the boundaries of the transboundary aquifers with surface expression >5 000 km^2 and, whenever possible, an indicative cross-section of each transboundary aquifer[2]. Regional workshops with national experts were held to discuss these data. The inventory unlocked much information from 'grey' literature and expert knowledge, which was previously only available at the national level. In general, indicators have been obtained for national country segment (TBA country unit), with harmonization discussed during the regional workshops.

WaterGAP model

The WaterGAP model was used for the computation of the values of a subset of the TWAP Groundwater core indicators for all TBAs > 20 000 km^2, and of projections to 2030 – 2050. Results can be displayed by model grid cell, whole TBA, or country segment.

All data from the global inventory and WaterGAP modelling are stored in the TWAP Groundwater data base, and a standardized description, or Aquifer Brief, has been compiled for each TBA, considering hydrogeological, socio-economic, environmental and legal and institutional (governance) aspects.

The combined and integrated data from the Global Inventory and WaterGAP model are the bases for the indicator-based assessment of the TBAs, describing their current state and including scenarios for 2030 and 2050.

Information management

A major element in the TWAP Groundwater Component is information management. A dedicated information management system (IMS) has been developed to facilitate storage, retrieval and visualization of results and underlying data. Final results and underlying data from the TBA and SIDS subcomponent have been uploaded to the IMS database. These data can be visualized as maps in the IMS viewer. Results and underlying data can be downloaded in excel format. The TBA and SIDS information sheets are also available for download (pdf-format). The IMS and its underlying database will facilitate periodic update of the inventory and characterization as well as monitoring of trends and impacts.

Project partners

UNESCO-IHP, in its capacity as lead agency for the TWAP Groundwater component, established a partnership of experts and organizations at the national, regional and global level, committed to:

(i) carry out the GEF-funded TWAP baseline assessment, adopting the methodology and modalities defined as a result of the TWAP design phase;

(ii) explore options for long-term periodic follow-up assessments and monitoring with non- GEF resources in order to ensure the sustainability of TWAP's Groundwater component.

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[2] Some TBAs with an area < 5 000 km^2 were included in the assessment as their regional significance was highlighted by the experts during the regional workshops. However, in this report, the 5 000 km^2 limit criteria is used as a general rule to refer to the TBAs assessed in the Global Inventory as compared with the WaterGAP model, which was applied only for TBAs > 20 000 km^2.

The partnership includes three categories of partners based on their specific roles and functions:

1. **The Core Group**, formed by UNESCO IHP and International Groundwater Resources Assessment Centre (IGRAC), along with the global network of UNESCO water-related centres and chairs. The core group had a central role in guiding and coordinating the TWAP groundwater assessment; it had overall responsibility, and directly performed parts of the assessment. Calling on a wide array of ongoing cooperation and joint activities with many partners, the core group provided the main pillars of the TWAP assessment through programmes such as the Internationally shared Aquifer Resources Management (ISARM) Initiative, the World-wide Hydrogeological Mapping and Assessment Programme (WHYMAP), the United Nations World Water Assessment Programme (WWAP), high-resolution global data sets on soils, land use and irrigation from FAO's AQUASTAT and other related programs, and IGRAC's Global Groundwater Information System (GGIS) as well as the Global Groundwater Monitoring Network.

2. **Regional Coordinators and Expert Networks**. Regional partners have contributed to the assessment with regional coordination mechanisms already in place; they provide the direct link to the countries. They have been responsible for organizing the acquisition of data on transboundary aquifers through existing (ISARM Americas) or newly established regional expert networks. Regional coordinators and National Experts served in particular as, having access to existing data and local information systems. In a few cases the management of Regional Coordination and Expert Networks and the promotion of country involvement was entrusted to Regional Organizations (UNESCWA, and the OSS).

3. **Key providers of expertise**. This group of partners includes: (i) Goethe University, Frankfurt, Germany, which had a central role in the modelling of selected core indicators for larger TBAs, including projections to 2030 and 2050 aimed at ensuring global coverage with harmonized data, and (ii) Simon Fraser University, Canada, which carried out the assessment of groundwater systems in SIDS, following the methodology defined by UNESCO IHP. In addition, UNESCO IHP senior advisors provided hydrogeological, environmental, socio-economic, legal and institutional expertise.

Inventory and Characterization of Transboundary Aquifers

Unlike all other water bodies, aquifers are located in the subsurface and visible only through the eyes of science – hydrogeology. As a consequence, groundwater resource boundaries, or aquifer boundaries, are often very poorly known and many aquifers remain unknown or only partly recognized as separate, often unconnected, entities. This is particularly true for transboundary aquifers, which are often not recognized as shared resources by countries because of differing geological lithostratigraphic approaches, lack of communication between countries, uneven availability of data, or sovereignty issues. Lack of recognition of the nature of shared resources increases their vulnerability to anthropogenic pressures. Hence the need for a systematic effort to identify aquifers that are transboundary and facilitate the recognition of their transboundary nature by countries sharing the resource (Inventory) and to provide a somewhat standardized description of their main characteristics in terms of hydrogeology, environmental role and implications, socio-economic value and present governance structure (characterization).

Prior to TWAP, 166 TBAs with surface expression of more than 5 000 km^2 were known to exist and were recognized by the countries sharing them, and aquifer boundaries and precise locations were known for only some of them. Thanks to TWAP, the TBA inventory now consists of a list of 199 TBAs over 5 000 km^2, with greatly improved accuracy in location and boundaries. In many cases the delineation of aquifer boundaries has been obtained using the physical boundaries of the host rock formation, a rough approximation of the boundaries of aquifer systems, which are always hard to identify with precision. A name has been assigned to each aquifer system (scientific, international, local).

Further, the inventory delimits areas with no information, or where information exists, but is not available.

The results of the inventory and characterization work can be accessed at: http://twapviewer.un-igrac.org.

Figure 1.1. Example of Transboundary Aquifer Information Sheet.

Transboundary Aquifer Information Sheet

Groundwater TWAP TRANSBOUNDARY WATERS ASSESSMENT PROGRAMME

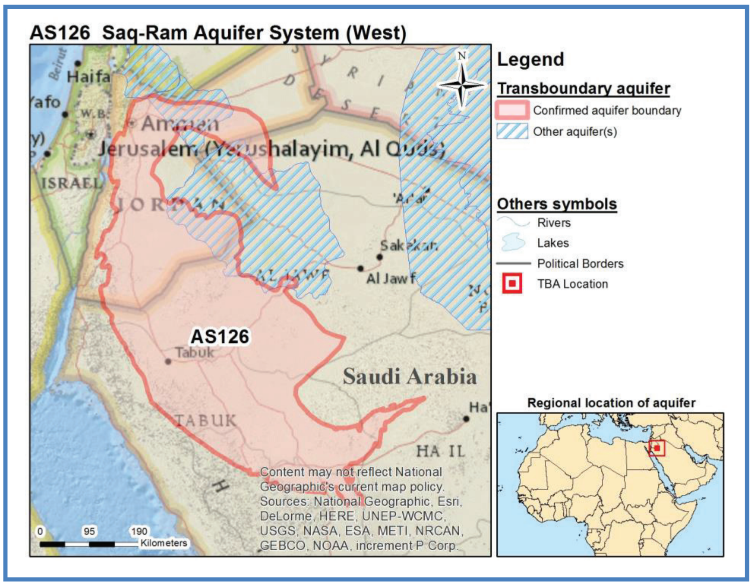
AS126 - Saq-Ram Aquifer System (West)

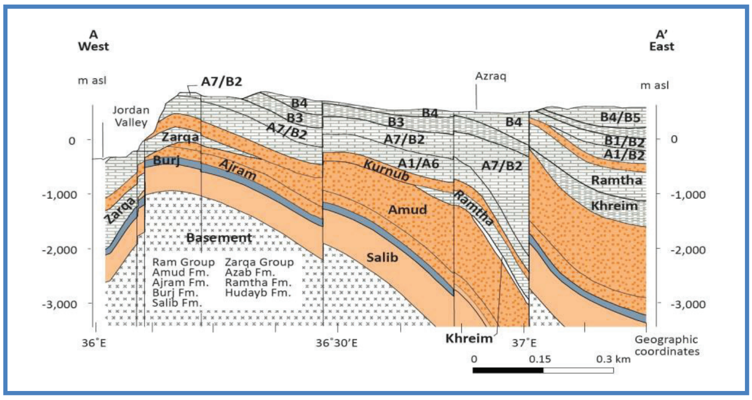
Geography

Total area TBA (km^2): 150 000
No. countries sharing: 2
Countries sharing: Jordan, Saudi Arabia
Population: 4 400 000
Climate zone: Arid
Rainfall (mm/yr): 74

Hydrogeology

Aquifer type: Multiple 3-layered, hydraulically connected
Degree of confinement: Mostly confined, some parts unconfined
Main Lithology: Sedimentary rocks - sandstones





Geological Cross-section across part of the Aquifer (E – W)

Map and cross-section are only provided for illustrative purposes. Dimensions are only approximate.

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Indicators

Indicators, capturing all major aspects critical for the purposes of the assessment, are the building blocks of the assessment methodology adopted. The set of indicators defined and developed for the purpose of TWAP Groundwater serves the following objectives:

(i) Capture the current state and projected trends of transboundary groundwater resources globally, as a basis for continuing, long-term monitoring;

(ii) Allow a comparative assessment of TBAs, in a region or globally, in terms of various parameters such as quantity and quality. These indicators and their integration into indices will in turn facilitate priority setting for GEF action and strategies;

(iii) Monitor the evolution of these parameters over time, i.e. the status of the TBAs, and hence provide an indication of the effectiveness of stress reduction measures being implemented by the GEF and by others.

Table 2 shows the aquifer description items covered by the ten TWAP Groundwater core current state and projected indicators.

Table 1.2. TWAP Groundwater core current state and projected indicators and thematic clusters

Thematic Cluster	Core Indicators (Projected indicators in bold)
Quantity	Groundwater Recharge (1.1) Groundwater Depletion (3.1)
Quantity	Groundwater natural background quality (1.3) Groundwater pollution (3.2)
Socio-economic	**Population density (4.1)** **Renewable groundwater per capita (1.2)** **Human dependence on groundwater (2.1)** **Groundwater development stress (4.2)**
Groundwater Governance	Transboundary legal framework (5.1) Transboundary institutional framework (5.2)

Summary of key findings

Groundwater recharge

TBAs with highest groundwater recharge rates exceeding 300 mm/yr are found in humid areas in the Amazon region, in Central Africa, and in South Asia (Amazonas aquifer, the Cuvette aquifer in Central Africa, the Indus River Plain aquifer, the East Ganges River Plain aquifer and the Khorat Plateau aquifer extending over Laos and Thailand).
TBAs characterized by low recharge rates (2 - 20 mm/yr) are found in Northwest Africa and the Arabian Peninsula. Recharges below 2 mm/yr were found in country segments in arid regions receiving very low groundwater recharge, namely the Nubian Sandstone Aquifer System in Chad, the northern fractions of the lake Chad Basin aquifer, the Taoudeni Basin aquifer and the Irhazer-Illuemeden Basin aquifers in Algeria, and the Uzbek part of the Syr Darya aquifer.

Return flows from irrigation over the Indus River Plain aquifer in Pakistan and India account for about 70 per cent and 40 per cent respectively of total groundwater recharge, including induced recharge. Over the Nubian Sandstone Aquifer System, return flows from irrigation were computed at 44 per cent (Egypt) and 38 per cent (Sudan) of total groundwater recharge. Over the East Ganges River Plain aquifer, 27 per cent of total groundwater recharge is contributed by return flows.

Considering projections of groundwater recharge, per-capita groundwater recharge will decrease from 2010 to 2030 in 211 country segments, taking into account both irrigation scenarios (AAI CONSTANT AAI Land SHIFT). From 2010 to 2050, 220 country segments will be affected by a decrease. In all cases, more country segments are negatively affected for the scenario with constant irrigated areas.

Low recharge values in TBAs may become potential risk factors when combined with high population densities, as in north-eastern Africa, parts of the Middle East and Northern India and Pakistan. In these areas, return flows from irrigation and other human-induced recharges appear to play a major role in the sustainability of groundwater resource utilization, adding a further element of vulnerability.

Groundwater depletion

The aquifers with the highest groundwater depletion rates worldwide are not transboundary. A comparison of aggregated and grid-based results reveals that most TBAs are located outside the major groundwater depletion regions of the world.

Mean annual groundwater depletion rates are very low to low in most country segments. In fact, only in three country segments - the Neogene Aquifer System in Syria, the Indus River Plain aquifer in India, and the merged Umm er Radhuma-Dammam Aquifer System in Bahrain – were computed to have medium-to-high mean annual groundwater depletion rates of 53 mm/yr, 28 mm/yr., and 222 mm/yr. Respectively. Indicators computed for the country segment in Bahrain are highly uncertain because of the small area of the country segment (535 km²).

Furthermore, the identified groundwater depletion rate in the Indian part of the Indus River Plain aquifer seems inconsistent at a first glance when compared to the small negative value of indicator 4.2a (-9 per cent) indicating a mean annual increase in groundwater storage. This inconsistency is attributable to the level of aggregation over the whole country segments. The grid-based distribution of indicator 3.1 and 4.2a reveals that very high depletion rates only occur in the northeastern part of the aquifer; while in the remaining area groundwater storage is increased (seen as slightly negative net abstractions from groundwater aggregated over the TBA). Groundwater depletion rates of almost 300 mm/yr in the northeast, however, are not counterbalanced by the slightly negative values in the remaining area, resulting in a groundwater depletion depth of 28 mm/yr in the Indian part of the Indus River Plain aquifer, and 10 mm/yr aggregated over the whole TBA.

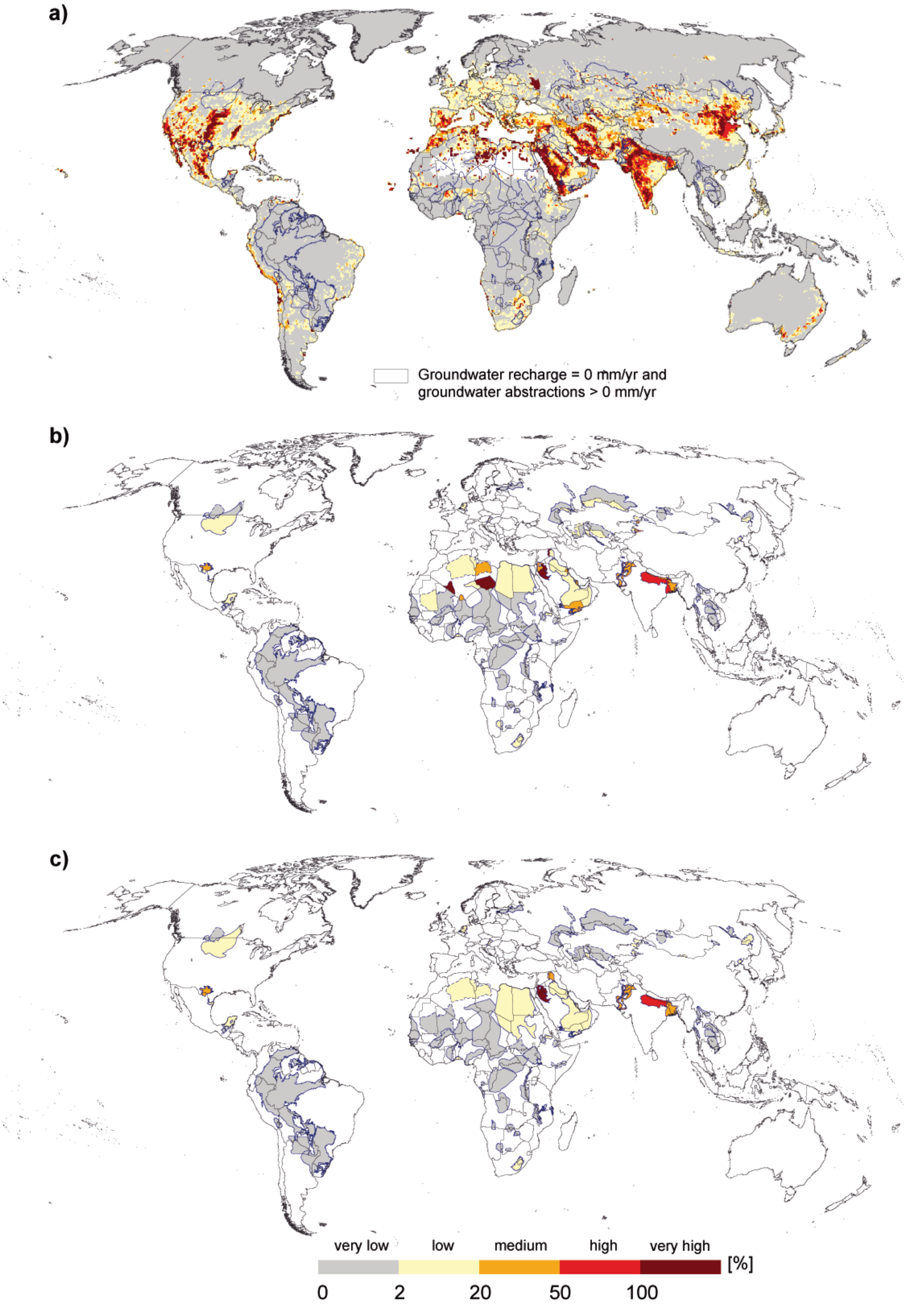
Groundwater development stress

Most TBAs are located outside high groundwater stress regions. Country segments with groundwater withdrawals exceeding 50 per cent of renewable groundwater resources (High development stress) include aquifers located in northern Africa (Lake Chad basin aquifer, Taoudeni basin aquifer), the Arabian Peninsula (Tawil Quaternary Aquifer System, Saq-Ram Aquifer System) and India (South of Outer Himalayas aquifer, East Ganges River Plain aquifer). Other country segments suffering from groundwater development stress satisfy between 35 and 91 per cent of their water demand from groundwater. In 20 out of 258 country segments, water withdrawals account for more than 20 per cent of groundwater recharge; 12 of them are characterized by a medium to high dependence on groundwater defined as the ratio of groundwater to total water abstraction > 40 per cent.

Eight additional country segments were identified with low groundwater development stress but potential "groundwater crowding": they show medium to very high dependence on groundwater (indicator 2.1 > 40 per cent) and low per-capita groundwater resources (indicator 1.2 < 1 000 m³/yr/cap). These country segments are located the Syr Darya aquifer (Uzbekistan), the Keta/Dahomey/Côtier basin aquifer (Nigeria, Togo, Benin, Ghana), the Mereb aquifer (Eritrea, Ethiopia), and the Aquifère du Rift (DR Congo).

The number of country segments suffering from medium to very high groundwater development stress in either 2030 or 2050 under the worst-case climate and irrigation scenario is projected to increase from 20 to 58, comprising all hotspots under current conditions.

Figure 1.2. Example (WaterGAP) – Indicator: Groundwater development stress by Grid Cell, Aquifer and Country Segment.



New hotspots are projected to develop mainly in Sub-Saharan Africa, China and Mexico. All country segments identified as hotspots in 2010 on the basis of the "groundwater crowding" criterion may reach at least medium groundwater development stress in 2030 or 2050. The highest future groundwater development stress values as well as the largest increases of groundwater development stress of up to 40 percentage points are projected for TBA country segments located in Botswana, the Middle East and North Africa region, South Asia, Uzbekistan, and Yucatán.

Population density, recharge and natural quality

In north-eastern Africa, parts of the Middle East and Northern India and Pakistan, low recharge values in TBAs are combined with high population densities. In these areas, return flows from irrigation and other human-induced recharge appear to play a major role in the sustainability of groundwater resource utilization. Very low natural quality (< 20 per cent of the aquifer area) coincides with TBAs highly impacted by irrigation return flows in densely populated areas with low to medium natural recharge, like the Nubian, Indus, Pre-Caspian TBAs.

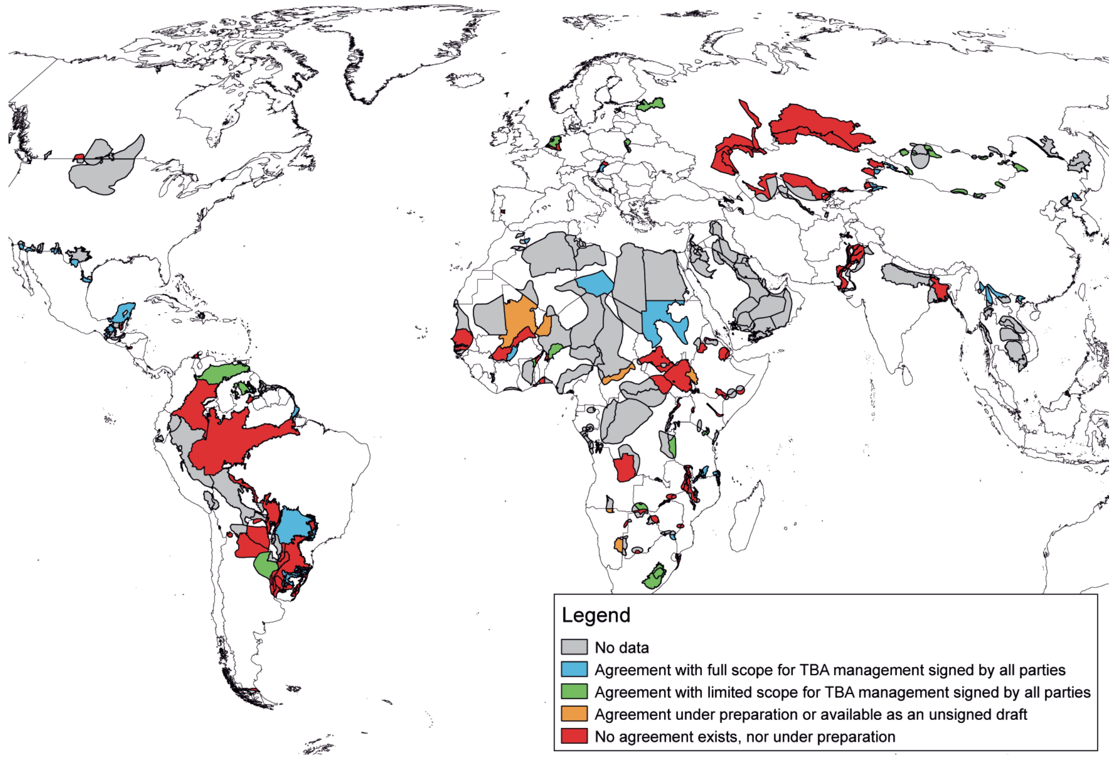
Aquifer buffering capacity

High residence times of groundwater, over 100 years and up to more than 1 000 years, are reported for a number of country segments of TBAs in the Sahel and Saharan Africa, Central and South Asia, where aquifer capacity to mitigate the effects of prolonged droughts is highly valuable.

Governance

When focusing on the most probable causes of tension among TBA countries, notably drawdown of groundwater levels, groundwater contamination from point and non-point sources of pollution and from salinization/saltwater intrusion, and man-made interferences with natural groundwater recharge processes, the TBAs exhibiting a combination of (a) no transboundary legal agreement or organization in place(the vast majority), and (b) limited

Figure 3. Example (Global inventory) – Indicator: transboundary legal frameworks by TBA country segment.



implementation measures at the domestic level are, on paper at least, those most at risk of conflict. At the global level, only eight TBAs have transboundary legal agreements. The patchy evidence on record prevents a serious juxtaposition of TBA-specific transboundary indicators and domestic 'implementation measures' indicators, and a resulting determination of which TBAs are more at risk of conflict than others.

It is clear, however, that the TBAs most at risk are those that exhibit actual or potential tension (for example groundwater development stress hotspots) and have no transboundary legal agreement or organization in place.

High-risk areas: current hotspots

Groundwater development stress, when combined with high human dependence on groundwater and low per capita renewable groundwater resources, determines situations of high risk for groundwater sustainability and human health. Table 3 presents these three indicators grouped into three high risk TBA clusters: 1) TBA-country segments with medium to very high groundwater development stress, and high human dependence on groundwater; 2) TBA-country segments with medium to very high groundwater development stress, and low human dependence on groundwater; 3) TBA-country segments with low groundwater development stress but low per-capita groundwater resources and medium to very high human dependence on groundwater ("groundwater crowding").

High-risk areas: future hotspots

Potential future hotspots at the TBA-country segments level using a worst-case scenario approach are shown in Figure 4.

Hotspots in 2030 or 2050 were identified, based on the worst-case scenario, using the following criteria:

- Groundwater Development Stress > 20 per cent and Human Dependence on Groundwater 40 per cent or higher in any of the four scenarios computed;
- Groundwater Development Stress > 20 per cent, but Dependence on Groundwater is low (indicator value < 40 per cent);
- Per-capita Groundwater Resources are less than 1 000 m^3/yr/ cap and the Dependence on Groundwater exceeds 40 per cent. Groundwater Development Stress is low or non-existent.

All TBA-country segments dentified as hotspots under current conditions were also identified as hotspots under future conditions except for the Aquifère du Rift in the Democratic Republic of the Congo, where the dependence on groundwater is expected to decrease to less than 40 per cent.

In total, 31 out of 258 TBA-country segments (12 per cent) extending over 21 TBAs present current or future groundwater stress with a high dependence on groundwater (very high risk).

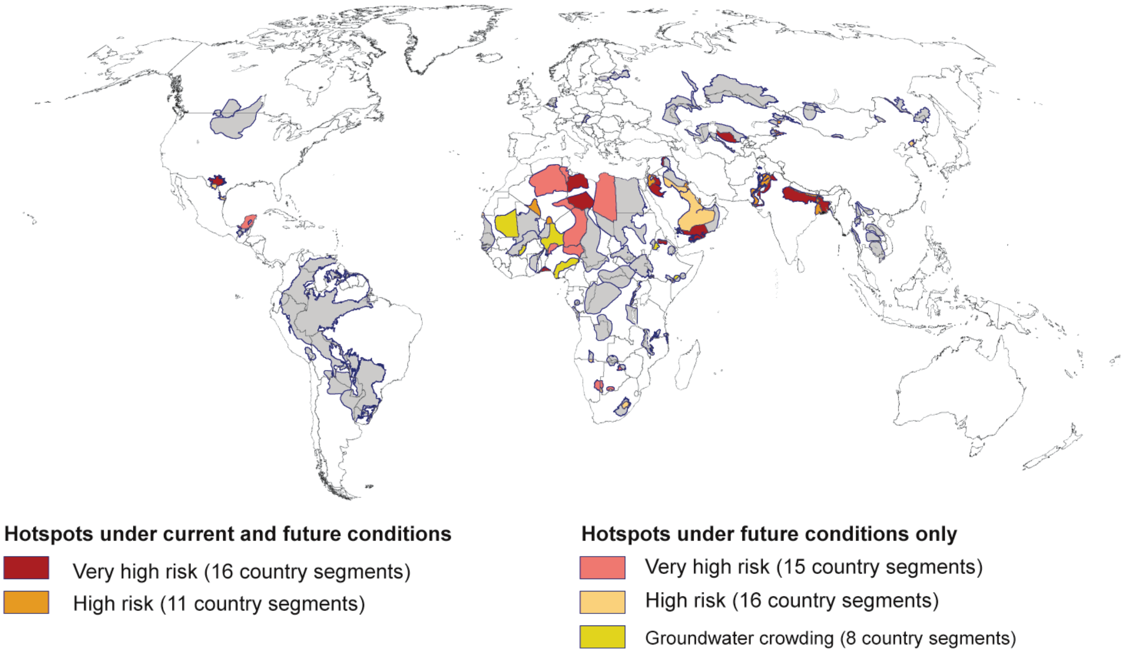
Two-thirds of the identified hotspots are located on the African continent and the Arabian Peninsula. The remaining TBA-country segments are distributed over Asia (Pakistan, India, Nepal, China, DPR Korea), and America (USA, Mexico, Chile). Furthermore, the level of groundwater development stress in the Austrian share of the Upper Pannonian Thermal aquifer is projected to rise more than 20 per cent based on results of at least one GCM.

Table 3. High risk TBA Clusters under current conditions

Aquifer name	Country Segment	Current-state indicators		
		Renewable groundwater per capita (1.2)	Human dependence on groundwater (2.1)	Groundwater development stress (4.2)
		[mm/yr/cap]	[%]	[%]
1. “Very high risk”: groundwater development stress (4.2) > 20% and dependence on groundwater (2.1) > 40%				
Lake Chad Basin	Libya	666	91	346
Northwest Sahara Aquifer System (NWSAS)	Libya	1 315	74	37
AS126_AS129 1)	Saudi Arabia	823	73	276
	Jordan	398	43	32
Neogene Aquifer System (North-West): Upper and Lower Fars	Syria	621	70	137
AS131_ 2)	Yemen	387	47	42
South of outer Himalayas aquifer	India	266	45	82
East Ganges River Plain aquifer	India	286	36	51
	Bangladesh	323	55	47
Edwards-Trinity-El Burro aquifer	USA	4 280	63	27
2. “High risk”: groundwater development stress (4.2) > 20% and dependence on groundwater (2.1) < 40%				
Taoudeni Basin aquifer	Algeria	5	16	156
Irhazer-Illuemeden Basin aquifer	Algeria	17	17	50
AS127_ 3)	Kuwait	59	2	32
AS131_ 2)	Qatar	101	3	29
	Bahrain	17	15	876
Indus River Plain aquifer	Pakistan	809	18	36
Tacheng Basin / Alakol aquifer	China	11 103	11	21
Illi River aquifer	China	2 594	11	20
3. “Groundwater crowding”: groundwater development stress (4.2) < 20%, dependence on groundwater (2.1) > 40% and per capita groundwater resources (1.2) < 1 000 m^3/yr/cap				
Syr Darya aquifer	Uzbekistan	558	50	20
Keta/Dahomey/Cotier basin aquifer	Nigeria	240	49	11
	Togo	256	71	8
	Benin	467	80	5
	Ghana	316	50	5
Mereb aquifer	Ethiopia	414	52	4
	Eritrea	436	53	4
Aquifère du Rift	DR Congo	432	42	2

1) AS126_AS129: Tawil Quaternary Aquifer System: Wadi Sirhan Basin, etc.
2) AS131_AS139_AS140_AS141_fractionAS128: Umm er Radhuma-Dammam Aquifer System (South), etc.
3) AS127_AS130_fraction AS128: Wasia-Biyadh-Aruma Aquifer System (North): Sakaka-Rutba, etc.

Figure 4. Potential future hotspots of groundwater development stress (indicator 4.2) at the TBA Country segments level using a worst-case scenario approach.



All eight country segments with "groundwater crowding" in current conditions suffer from development stress >20% under future conditions and are thus classified in the "Very high risk" category (current and future conditions).

Final remarks

Worldwide, the majority of transboundary aquifers with surface expression greater than 5 000 km^2 are located outside regions highly affected by groundwater development stress, and show very low depletion rates of less than 2 mm/yr in most regions of the world. Human dependence on transboundary groundwater is still generally low to very low in 193 out of the total 258 TBA national segments analysed.

It is therefore possible to draw the conclusion that groundwater resources are still potentially available for development in transboundary groundwater basins and aquifer systems. When considering that this assessment, largely based on modelling, has necessarily not taken into consideration the vertical dimension of aquifers, that is the existence and thickness of multi-layered systems and deep-seated aquifers, the quantity of these still unexploited reserves becomes very large.

The high residence times of groundwater, which has been found by this assessment to be of more than 100 years and up to more than 1 000 years for a number of TBAs in the Sahel and Saharan Africa, Central and South Asia, adds value to these transboundary resources because of their capacity to mitigate the effects of prolonged climatic extremes.

The number of TBA hotspots resulting from combinations of high human dependence, low renewable groundwater per capita, and high extraction/recharge ratios, is rather limited. Under the worst-case climate and irrigation scenario, the national segments of transboundary aquifers in the high risk and very high risk hotspot categories are expected to increase between now and 2050 from 20 to 58. New hotspots, mainly driven by population pressures, are projected to develop mainly in Sub-Saharan Africa, China and Mexico. The highest future groundwater development stress values as well as the largest increases of groundwater development stress of up to 40 percentage points are projected for TBA country segments located in Botswana, the Middle East and North Africa region, South Asia, Uzbekistan, and Yucatán. For the future, eight new country segments were identified as potential hotspots of "groundwater crowding" (low per-capita groundwater resources and medium to very high dependence on groundwater), all of them in West or East Africa.

The assessment failed to produce enough information on anthropogenic pollution in TBAs to enable conclusions at the global level to be drawn. However the assessment has highlighted that very low background groundwater quality characterizes all TBAs highly impacted by irrigation return flows in densely populated areas with low to medium natural recharge, such as the Nubian, Indus, Pre-Caspian TBAs.

These findings of TWAP Groundwater highlight the still largely untapped potential of transboundary groundwater systems and delineate main areas at higher risk of groundwater stress and degradation. The assessment has also allowed identification of critical factors that may prevent, or hinder our ability to sustainably exploit these critically important shared resources.

The lack of adequate groundwater governance at the global, regional and local levels *"…hinders the achievement of groundwater resources management goals such as resource sustainability, water security, economic development, equitable access to benefits from water and conservation of ecosystems."*[3] This authoritative statement is even more valid when applied to transboundary groundwater. The assessment has in fact confirmed that governance and institutional frameworks for TBAs are totally absent, with the notable exception of five cases, three of which in Africa.

The assessment has also provided evidence of an alarming lack of knowledge and modern data on groundwater in general, and TBAs in particular. Indeed without the help of modelling, this assessment would not have been possible. The information received through the widely-distributed questionnaires, notwithstanding the highly appreciated efforts of hundreds of national and regional experts, undoubtedly reflects the lack of quantitative, modern standardized data on many key groundwater parameters, and the generalized limited knowledge of the subsurface and its water resources. The failure to provide even minimal information on groundwater dependent ecosystems has been surprising.

Moreover, issues of sovereignty, the widely perceived need for official endorsement of technical data, and the sensitivity and growingly strategic nature of transboundary water resources, are among the factors that have precluded a greater, more proactive response to questionnaires. The limited financial resources have also played a constraining role.

Modelling has allowed estimates of all hydrogeological and socio-economic indicators for all major TBAs and their national segments to be obtained, and their projections to 2030 and 2050 be made. For the environmental and governance indicators, the only sources of information were the questionnaires, and hence values for these indicators are available only for a fraction of all TBAs. The use of models, increasingly indispensable with their ability to fill data gaps, simulate, extrapolate and forecast, has, however its limitations, which are particularly obvious in the case of aquifers. Global Models are constrained by lack of ground data, and by their inability to consider the three-dimensional nature of aquifers and the complexities of subsurface water flow and recharge patterns. Their outputs must be considered with caution.

All this notwithstanding, TWAP Groundwater was able to establish the first Global Inventory of TBAs, contained in a publicly open TWAP Groundwater Information Management System, and to produce standardized data collection and assessment methodologies, which are now being already applied at the single TBA scale in Sub-Saharan Africa, Central Asia, and Central America[4]. These are cornerstone achievements and resources now available to all.

Useful elements have been gathered to help identify areas where transboundary groundwater use is being progressively constrained by degradation of background quality, development stress, and lack of governance frameworks. High-risk areas of future groundwater stress have been identified in consideration of worst-case climatic and agricultural scenarios. The role of TBAs and their still largely untapped groundwater resources in preventing, buffering or mitigating impacts of global change on human livelihoods and the environment has been highlighted.

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[3] Groundwater Governance Project, Global Diagnostic. GEF, FAO, UNESCO, World Bank and IAH, 2015.

[4] The TWAP Level 2 detailed assessment, which is presently being implemented by UNESCO IHP in three representative TBAs with the generous financial support of the Swiss Government.

2. Assessment of groundwater systems of Small Island Developing States

SIDS are all island developing countries and territories with a population of less than 5 million people. While both the UN and the Commonwealth Secretariat use population as the benchmark for determining smallness, there is no officially agreed international definition. Factors such as small size (land and population), insularity and remoteness, limited natural resource base and problems associated with the local environment, are all obstacles to achieving efficiency in livelihood development, economic production, environmental sustainability and climate change adaptation.

A two-step approach was adopted for the assessment of the SIDS:

(i) Preliminary data collection: data were sourced initially from easily-accessible global and regional publications and existing and accessible databases as recommended in the TWAP TBA Methodology. The same global data sources were used, where possible, for acquiring population statistics, climate data and climate projections, and geo-referenced data such as island boundaries and digital elevation models.

(ii) SIDS questionnaires survey: information provided by experts through questionnaires was integrated with the preliminary assessment data.

For the SIDS subcomponent it was not possible to make use of a global model, as the islands are too small. The assessment of the SIDS therefore contains no scenario analyses for 2030 and 2050.

The assessment focuses on 42 SIDS (Table 4). It takes as primary spatial unit the whole island state, includes aquifer properties and time-dependent variables that were compiled from the literature, and the results of questionnaires sent to national experts. A suite of indicators, common to the TWAP TBA assessment, was evaluated on the basis of the above information. For each SIDS, a hydrogeological profile has been developed consisting of a geological map and cross-section, and key summary information concerning the hydrogeology.

Table 4. List of target islands for SIDS assessment

State	Target Island	Population of Island (year)	Terrain
AIMS Region (6 SIDS):			
Cape Verde	Santiago	240 000 (2010)	Rugged, rocky, volcanic
Comoros	Njazidja	316 600 (2006)	Volcanic islands
Maldives	Male	105 000 (2012)	Coral limestone
Mauritius	Mauritius	1 236 817 (2011)	Volcanic, mountainous
Sao Tome and Principe	Sao Tome	157 500 (2011)	Volcanic, mountainous
Seychelles	Mahe	78 539 (2010)	Volcanic, sands
Caribbean (17 SIDS):			
Anguila	Anguila	13 452 (2011)	Flat low-lying coral and limestone
Antigua and Barbuda	Antigua	81 161 (2011)	Volcanic and low-lying limestone and coral
Aruba	Aruba	103 504 (2011)	Karstic Limestone
Barbados	Barbados	277 821 (2010)	Karstic Limestone
British Virgin Islands	Tortola	23 908 (2005)	Hilly volcanic islands and flat coral islands
Dominica	Dominica	71 293 (2011)	Rugged volcanic mountains
Grenada	Grenada	103 328 (2011)	Volcanic, mountainous
Jamaica	Jamaica	2 695 543 (2010)	Karstic limestone

State	Target Island	Population of Island (year)	Terrain
Montserrat	Montserrat	5 164 (2012)	Volcanic mountains, coastal lowland
Netherlands Antilles	Curaçao	150 563 (2011)	Carbonates, volcanic interiors
Puerto Rico	Puerto Rico	3 725 789 (2010)	Volcanic, limestone
St Kitts and Nevis	Saint Christopher (i.e. Saint Kitts)	35 217 (2001)	Volcanic, mountainous interiors
Saint Lucia	Saint Lucia	165 770 (2010)	Volcanic, mountainous, broad valleys
Saint Vincent and the Grenadines	Saint Vincent and The Grenadines	106 253 (2001)	Volcanic, mountainous
The Bahamas	New Providence	248 948 (2010)	Karstic limestone
Trinidad and Tobago	Trinidad	1 267 145 (2011)	Limestone
US Virgin Islands	Saint Croix	50 601 (2010)	Limestone
The Pacific (19 SIDS):			
American Samoa	Tutuila	55 876 (2000)	5 volcanic islands, 2 coral atolls
Belau/Palau	Koror/Oreor	11 560 (2005)	Volcanic
C'wealth. of the Northern Marianas	Saipan	48 220 (2010)	S: limestone + reefs, N: volcanic
Cook Islands	Rarotonga	10 572 (2011)	N: low coral atolls; S: volcanic, hilly
Fiji	Viti Levu	661 997 (2007)	Volcanic mountains, coral atolls
French Polynesia	Tahiti	183 645 (2012)	Mix of rugged volcanic and low lying islands
Guam	Guam	159 358 (2010)	Limestone
Kiribati	Tawara/Kiritimati	40 529 (2010)	Limestone
Marshall Islands	Majuro	27 797 (2011)	Low coral limestone and sand
Federates States of Micronesia	Pohnpei	36 196 (2010)	Volcanic, mountainous, coral atolls
Nauru	Nauru	10 084 (2011)	Limestone
New Caledonia	Grande Terre	245 580 (2009)	Metamorphic and sedimentary
Niue	Niue	1 625 (2006)	Limestone cliffs, central plateau
Samoa	Upolu	143 418 (2011)	Basalt
Solomon Islands	Malaita	137 596 (2009)	Limestone, volcanic
Timor-Leste	Timor-Leste	1 066 582 (2010)	Limestone
Tonga	Tongatapu	75 416 (2011)	Karstic limestone
Tuvalu	Funafati	6 194 (2012)	Limestone
Vanuatu	Efate	65 829 (2009)	Limestone, volcanic

Identification of SIDS aquifer systems object of the assessment[5]

An overview of the world's SIDS, according to the SIDS portal of UNDESA lists 51 Small Island States, four of which are on continents, four are larger than 50 000 km^2 in size, and four have more than 5 million inhabitants. Three criteria have been chosen as appropriate to reduce the number of SIDS to be included in assessment. The first is size: setting a maximum of 50 000 km^2 eliminates four countries: Cuba, Guyana, Suriname and Papua New Guinea. The second is that the state should consist of one or more islands (or part of islands) and not be located on a continent. Use of this criterion deletes another two countries: Guinea-Bissau and Belize. Taking as a third criterion that the number of inhabitants should not exceed 5 million leads to also deleting the Dominican Republic and Haiti from the list. Combining these criteria reduces the number of SIDS to be included in TWAP from 51 to 42.

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[5] Given the high level of human dependence on groundwater in SIDS, the assessment will also encompass aquifers in SIDS, whether or not these are transboundary.

The aim of this project is to assess, quantitatively or quantitatively, the set of pre-defined TWAP groundwater indicators for each SIDS. The work consisted of the following steps:

1. Conduct a preliminary assessment of variables by compiling data and information from publications and existing and accessible datasets. The approach, as far as possible, used a consistent methodology for assessing all the SIDS as a group;
2. Develop and distribute a questionnaire to regional expert networks and knowledgeable experts on groundwater resources within each SIDS;
3. Integrate the results of the questionnaire with the preliminary assessment of variables to define the current-state indicators;
4. Assess links between water systems. Within the context of SIDS, the most important link is between the aquifer and the ocean because of the potential for saltwater intrusion;
5. Generate a hydrogeological profile for a representative island for each SIDS;
6. Integrate GIS layers and a related database summarizing the attributes of each SIDS, along with supporting references into the TWAP Groundwater Information Management System.

The 42 SIDS are situated within three regions: AIMS (Africa, Indian Ocean, Mediterranean and South China Sea) Region; Caribbean; and Pacific. Thirty of the 42 SIDS comprise more than one island (up to 40 for French Polynesia). It was therefore not practical to collect information on an island-by-island basis. Instead, the strategy for this assessment was to select one representative island within each SIDS. Typically, the representative island had the largest population. Table 4 shows the list of the 42 SIDS covered by the assessment, and the representative island for each.

Island hydrogeological profiles

For each SIDS, a representative hydrogeological profile was generated. This consisted of a location map, a generalized geological map and a representative cross-section. Also included on the profile are the relevant statistics: island area, maximum elevation, aquifer lithology, average annual precipitation, calculated Actual Evapotranspiration (AET), recharge, maximum aquifer thickness[6], groundwater volume, groundwater volume extracted, and predominant natural groundwater quality. The statistics are only provided for the dominant aquifer lithology, identified on the geological map legend. Additionally, the shape of the freshwater lens is approximated on the basis of questionnaire results, if provided, for the near-coast hydrogeological setting. Thicker lenses are assumed to develop under high topography areas and these were approximated on the cross-sections[7].

Significant effort was invested in the generation of these island profiles. A customized hydrogeological profile was generated for each SIDS. All Island Profiles are available at http://twapviewer.un-igrac.org.

Assigning indicators

The TWAP Groundwater Methodology describes how links between the groundwater system and other water systems can be identified. Within the context of SIDS, the most important link is between the aquifer and the ocean because of the potential for saltwater intrusion. Indicators relevant to this aspect of links were assessed both qualitatively and quantitatively. First, for each island, a hydrogeological cross-section was constructed in such a fashion as to show the approximate depth of the saltwater-freshwater interface as a quantitative, although uncertain estimate. In addition, semi-qualitative information was collected concerning the quality of water (fresh, brackish, saline), and whether the extent of saltwater intrusion has increased over the period (2000-2010).

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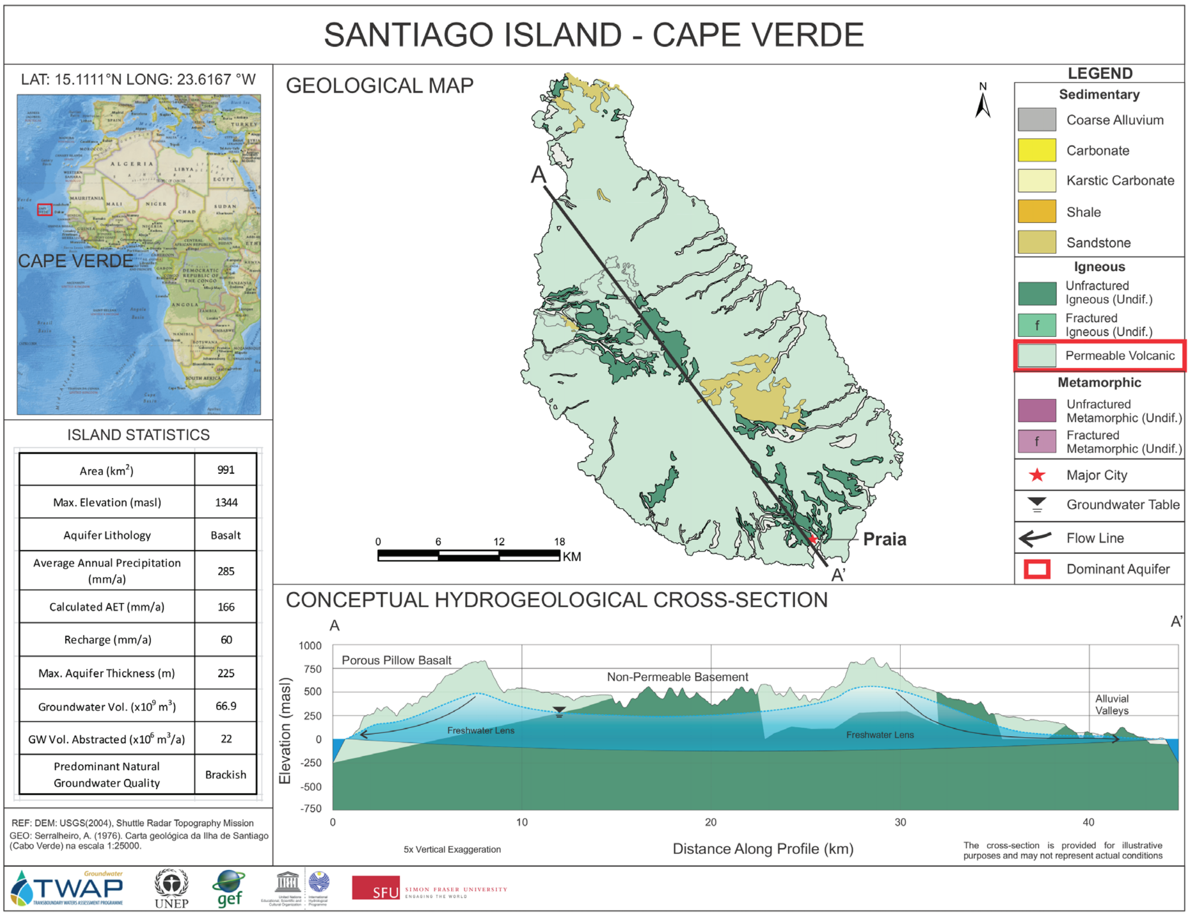
[6] On an island, the aquifer thickness coincides with the freshwater lens thickness.

[7] According to the Ghyben – Herzberg Principle, when fresh groundwater floats over saltwater, there are 40 feet of freshwater below sea level for every foot above sea level.

Figure 5. Example of SIDS hydrogeological profile.



ISLAND STATISTICS

Area (km^2)	991
Max. Elevation (masl)	1344
Aquifer Lithology	Basalt
Average Annual Precipitation (mm/a)	285
Calculated AET (mm/a)	166
Recharge (mm/a)	60
Max. Aquifer Thickness (m)	225
Groundwater Vol. (x10^9 m^3)	66.9
GW Vol. Abstracted (x10^6 m^3/a)	22
Predominant Natural Groundwater Quality	Brackish

REF: DEM: USGS(2004), Shuttle Radar Topography Mission
GEO: Serralheiro, A. (1976). Carta geológica da Ilha de Santiago (Cabo Verde) na escala 1:25000.

All data gathered as part of the assessment of groundwater systems in SIDS, including aquifer properties, values of time-dependent variables, and computed indicators, are available at www.twap.isarm.org. All hydrogeological profiles of the SIDS part of the assessment are available at http://twapviewer.un-igrac.org.

Final Remarks

This wealth of information, although of variable reliability and limited to selected islands in the case of SIDS archipelagos, represents the first baseline global assessment of the status of groundwater in SIDS, covering all major and more densely populated island states of the world (42) below a surface threshold of 50 000 km^2. The hydrogeological characterization and the socio-economic and environmental data collected have allowed the computation of 21 indicators, including the ten TWAP core indicators and the indicator for saltwater intrusion. All this information lends itself to a number of elaborations, targeted diagnoses, prioritization processes of interventions and investments by countries and ODA providers and IFIs.

As part of TWAP, the analysis has focused on translating the core indicators related to quality, quantity and socio-economic aspects into risk categories (low to very low, medium, high to very high) to allow a first assessment of groundwater sustainability in the islands, which is in many cases inextricably linked to human and ecosystem health[8]. Population density appears to be the main driver of water stress, with values ranging from medium to very high in all

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[8] The groundwater development stress indicator has not been included in the analysis given its limited significance caused by the scarcity of data on aquifer surfaces.

but one of the islands. This reflects in the large number of islands (71 per cent) at risk of water scarcity (medium to very low per capita renewable groundwater), with a peak of 91 per cent for low-lying islands. Risk due to groundwater anthropogenic pollution affects 73 per cent of all 42 islands, compounded in 19 of the 31 islands that provided relevant data by seawater intrusion and natural salinization. High human groundwater dependence represents a risk factor in 10 per cent of the Caribbean and Atlantic/Indian Ocean islands, and 72 per cent of the Pacific cluster islands for which data was available. This marked difference among regions probably reflects differences in the availability of alternative water resources, either surface water or seawater desalinization (for example the Bahamas), and/or different stages of socio-economic development.

On many small islands, groundwater abstraction only occurs within small, thin, alluvial (or carbonate) aquifers along the coastlines. In many cases, these aquifers may constitute the main groundwater supply for the island, as accessing the groundwater contained within more complex, albeit possibly highly productive, fractured volcanic formations at higher elevations poses significant challenges. Although all islands are vulnerable to saltwater intrusion, SIDS reliant on small coastal aquifers are at higher risk of saltwater contamination from sea level rise, pumping, and wave overwash events.

The situation that emerges from this analysis calls for immediate attention. In the absence of coordinated, sustained remedial national and international action, low-lying islands in the Pacific, highly dependent on scarce, polluted and growingly saline groundwater resources and impacted by climatic variability and change, face dramatic choices. In many other islands, degradation of groundwater quality and growing demands are posing short-medium term threats to human health, and impairing the provision of ecosystem services of great economic relevance.

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Table 5. Assessment of Risk Factors in SIDS

a) Risk Factors All SIDS

Blue: Low to very Low; Orange: Medium; Red:High to Very High; Blank:NA

SIDS	Recharge/ Capita	Nat. Water Quality	Human GW Dependence	Pollution	Saltwater Intrusion	Population Density
Atlantic and Indian Ocean						
Cape Verde	🟥	🟧	🟦	🟧	🟥	🟥
Comoros	🟧	🟦	🟦	🟧	🟦	🟥
Maldives	🟥	🟥	🟦	🟥	🟥	🟥
Mauritius	🟧	🟦	🟦	🟧	🟦	🟥
Sao Tome and Principe	🟧		🟦	🟦		🟥
Seychelles	🟥	🟥	🟦	🟥	🟥	🟥
Caribbean						
Anguilla	🟧	🟥		🟥	🟥	🟥
Antigua and Barbuda	🟧		🟦	🟥		🟥
Aruba	🟥	🟥	🟦	🟦	🟥	🟥
Barbados	🟥	🟦	🟦	🟥	🟦	🟥
British Virgin Islands	🟧	🟥		🟥	🟥	🟥
Dominica	🟦	🟥	🟦	🟧	🟥	🟧
Grenada	🟥		🟦	🟧		🟥
Jamaica	🟧	🟥	🟥	🟧	🟦	🟥
Montserrat	🟦			🟥		🟧
Netherland Antilles	🟥	🟥		🟧	🟥	🟥
Puerto Rico	🟧	🟦	🟦	🟧	🟦	🟥
St Kitts and Nevis	🟧	🟦	🟥	🟥	🟦	🟥
Saint Lucia	🟧	🟥	🟦	🟧	🟥	🟥
Saint Vincent and Grenadines	🟧		🟦	🟧		🟥
The Bahamas	🟥	🟥	🟦	🟥	🟥	🟥
Trinidad and Tobago	🟧		🟦	🟥		🟥
US Virgin islands	🟥	🟦	🟦	🟥	🟥	🟥
Pacific						
American Samoa	🟧	🟦	🟥	🟥	🟧	🟥
Belau/Palau	🟧			🟥		🟥
C'wealth of N. Marianas	🟧	🟦	🟥	🟥	🟥	🟥
Cook Islands	🟧	🟦	🟦	🟧	🟦	🟥
Fiji	🟦	🟦	🟦	🟦	🟦	🟥
French Polynesia	🟦	🟦	🟥	🟦	🟦	🟥
Guam	🟦	🟦	🟥	🟥	🟦	🟥
Kiribati	🟥	🟥		🟥	🟥	🟥
Marshall Islands	🟥	🟦	🟥	🟥	🟥	🟥
Federate States of Micronesia	🟦	🟦		🟦	🟦	🟥
Nauru	🟧	🟥	🟥	🟧	🟥	🟥
New Caledonia	🟦	🟦	🟧	🟦	🟧	🟧
Niue	🟦	🟦	🟥	🟧	🟦	🟦
Samoa	🟦	🟦		🟧		🟥
Solomon Islands	🟦			🟦		🟧
Timor-Leste	🟦	🟦	🟦	🟦	🟦	🟧

Tonga	🟧	🟦	⬜	🟧	🟧	🟥
Tuvalu	🟥	🟥	⬜	🟧	🟥	🟥
Vanuatu	🟦	⬜	⬜	🟦	⬜	🟧

b) Risk Factors – Mountainous SIDS

SIDS	Recharge/ Capita	Nat. Water Quality	Human GW Dependence	Pollution	Saltwater Intrusion	Population Density
Atlantic and Indian Ocean						
Cape Verde	🟥	🟧	🟦	🟧	🟥	🟥
Comoros	🟧	🟦	🟦	🟧	🟦	🟥
Mauritius	🟧	🟦	🟦	🟧	🟦	🟥
Sao Tome and Principe	🟧	⬜	🟦	🟦	⬜	🟥
Caribbean						
Antigua and Barbuda	🟧	⬜	🟦	🟥	⬜	🟥
British Virgin Islands	🟧	🟥	⬜	🟥	🟥	🟥
Dominica	🟦	🟥	🟦	🟧	🟥	🟧
Grenada	🟥	⬜	🟦	🟧	⬜	🟥
Jamaica	🟧	🟥	🟥	🟧	🟦	🟥
Montserrat	🟦	⬜	⬜	🟥	⬜	🟧
Puerto Rico	🟧	🟦	🟦	🟧	🟦	🟥
St Kitts and Nevis	🟧	🟦	🟥	🟥	🟦	🟥
Saint Lucia	🟧	🟥	🟦	🟧	🟥	🟥
Saint Vincent and Grenadines	🟧	⬜	🟦	🟧	⬜	🟥
Trinidad and Tobago	🟧	⬜	🟦	🟥	⬜	🟥
Pacific						
American Samoa	🟧	🟦	🟥	🟥	🟧	🟥
Belau/Palau	🟧	⬜	⬜	🟥	⬜	🟥
C'wealth of N. Marianas	🟧	🟦	🟥	🟥	🟥	🟥
Cook Islands	🟧	🟦	🟦	🟧	🟦	🟥
Fiji	🟦	🟦	🟦	🟦	🟦	🟥
French Polynesia	🟦	🟦	🟥	🟦	🟦	🟥
Federate States of Micronesia	🟦	🟦	⬜	🟦	🟦	🟥
New Caledonia	🟦	🟦	🟧	🟦	🟧	🟧
Niue	🟦	🟦	🟥	🟧	🟦	🟦
Samoa	🟦	🟦	⬜	🟧	⬜	🟥
Solomon Islands	🟦	⬜	⬜	🟦	⬜	🟧
Timor-Leste	🟦	🟦	🟦	🟦	🟦	🟧
Vanuatu	🟦	⬜	⬜	🟦	⬜	🟧

C) Risk Factors – Low-lying SIDS

SIDS	Recharge/ Capita	Nat. Water Quality	Human GW Dependence	Pollution	Saltwater Intrusion	Population Density
Atlantic and Indian Ocean						
Maldives	🟥	🟥	🟦	🟥	🟥	🟥
Seychelles	🟥	🟥	🟦	🟥	🟥	🟥
Caribbean						
Anguilla	🟧	🟥		🟥	🟥	🟥
Aruba	🟥	🟥	🟦	🟦	🟥	🟥
Barbados	🟥	🟦	🟦	🟥	🟦	🟥
The Bahamas	🟥	🟥	🟦	🟥	🟥	🟥
US Virgin islands	🟥	🟦	🟦	🟥	🟥	🟥
Pacific						
Guam	🟦	🟦	🟥	🟥	🟦	🟥
Kiribati	🟥	🟥		🟥	🟥	🟥
Nauru	🟧	🟥	🟥	🟧	🟥	🟥
New Caledonia	🟦	🟦	🟧	🟦	🟧	🟧
Tonga	🟧	🟦		🟧	🟧	🟥
Tuvalu	🟥	🟥		🟧	🟥	🟥

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Part A. Project Approach

Chapter 1

Methods and objectives

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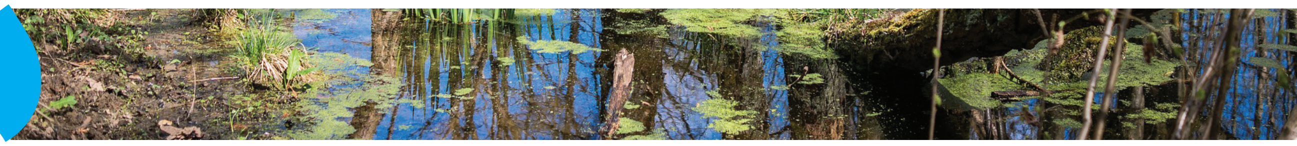
Chapter Citation: Merla, A., Nijsten, G.J., Dumont, A., Aureli, A. (2016). Chapter 1: Methods and objectives. In UNESCO-IHP and UNEP (2016). Transboundary Aquifers and Groundwater Systems of Small Island Developing States: Status and Trends. United Nations Environment Programme, Nairobi, pp. 1–7.

1. Methods and objectives



Groundwater is an integral part of the water cycle, inextricably linked to surface water and ecosystems. It is ubiquitous and represents 99 per cent of all liquid freshwater on Earth. It is being exploited aggressively in many regions of the world, and in a number of cases represents the only water available for human uses. A tremendous increase in the utilization of groundwater has occurred in the past few decades thanks to the availability of new and cheaper drilling and pumping technologies. Hydrogeologists refer to this drastic change in groundwater utilization as ‘the silent revolution’, since it has occurred in many countries in an unplanned and totally uncontrolled way. It went almost unnoticed.

People’s initial attitude of taking groundwater – a fundamental natural resource and vital component of our environment – for granted and simply exploiting it according to individual demands has prevailed in most countries of the world until recently, when demographic pressures, economic and technological development, growing climatic variability and other factors have triggered unprecedented changes in the state of our groundwater systems, which have resulted in a growing awareness of the finiteness and vulnerability of this critical resource. Now we have come to realize that, without proper knowledge and management, this huge resource can be rapidly and irreversibly degraded. Pollution of aquifers is hard to reverse; over-exploitation may have permanent impacts on aquifer resilience and behaviour. We have also realized that many land and water ecosystems depend on groundwater regimes, as is the case for most semi-arid alluvial plains, wetlands, coastal habitats, and even coastal marine environments. Groundwater cuts across basins and landscapes, sustaining ecosystems and biodiversity, mitigating the impacts of climatic fluctuations, contributing to human health and social-economic development. It is now apparent that groundwater, from the shallowest unconfined aquifers to the deepest hidden reserves, has a critical role to play in addressing the new challenges of adapting to the realities of a changing climate and combating desertification.

While groundwater is an inseparable part of overall water resource management, it deserves special attention because of its hidden, invisible nature, and its high stock-to-flow ratio. The common pool resource characteristics of groundwater, the close interaction between groundwater and land use and the often-limited understanding among policy makers of its characteristics and of the geological processes that control its behaviour, are additional challenging features. In spite of the efforts being made across the planet to introduce some degree of management to the use of this invaluable resource, groundwater remains largely unknown, and, with some notable exceptions, its exploitation at the global level is far from sustainable. Groundwater resources are being rapidly degraded in terms of quality and quantity, and the opportunities that currently exist for the strategic expansion of groundwater use are being compromised, or simply remain unknown to stakeholders and resource administrators.

In response to this new awareness, the need for groundwater resource assessment and management has come to the forefront of the global agenda on sustainable development. Modern, comprehensive assessments of the groundwater resources available in a given territory are indispensable tools for monitoring, protecting and managing, sustainably and to their full extent, these strategic yet invisible resources, which reside in the subsurface, from shallow near-surface levels down to depths of thousands of metres.

Assessing groundwater means identifying the aquifer systems present in the subsurface at different depths and reaching an adequate understanding of their characteristics and functioning. Eventually, it means understanding the subsurface and its resources.

Deep aquifers are still largely unknown, and so far are only sparsely tapped around the world for abstracting freshwater. Having no or only little recharge, they are mainly non-renewable resources. However they certainly present opportunities for more intensive exploitation, in particular as an emergency resource and as a buffer for mitigating climate change impacts.

The Global Environment Facility recognizing that *"Groundwater exemplifies, possibly better than any other element of the natural environment, the concept of interlinkages which GEF is striving to translate into operational guidelines for addressing desertification, climate change adaptation and the protection of groundwater dependent ecosystems, such as wetlands", the Strategic Technical Advisory Panel (STAP)*, has fostered, through its International Waters focal area and strategies, cooperation among countries sharing aquifers in the assessment and joint management of this critical resource.

The Transboundary Waters Assessment Programme, with its ground-breaking Transboundary Aquifers Component represents a major effort to raise awareness of policy makers, Official Development Assistance (ODA) providers and International Financial Institutions (IFIs), and the scientific community, on the existence, global distribution, main characteristics, current state and likely future trends of all known major transboundary aquifers (>5 000km^2), where a large part of the world's groundwater resources is stored, and where management complexity is compounded by the multi-country shared nature of the resource.

1.1. Objectives and outputs of TWAP Groundwater Component

The overall goals of the Groundwater component of TWAP were to:

1) Provide a description of the present conditions of transboundary aquifers (TBAs) with areal extent >5 000km^2, and aquifers in Small Island Developing States (SIDS), which will enable the GEF IW Focal Area to determine priority aquifers/regions for resources allocation;
(2) Bring to the global attention the major issues, concerns and hotspots of these transboundary aquifer systems and SIDS aquifers, and catalyse action.

The results of the TWAP Groundwater assessment will provide elements to help the GEF and other interested parties to find answers to the following questions, among others**:**

- (i) What human and ecosystem uses of the water resources are currently affected or impaired (use conflicts, depletion, and degradation)?
- (ii) How will water conditions and uses develop during the coming decades? Global change is projected to produce increased pressures during the coming decades, such as higher water demands for food security/irrigation and domestic use, more intensive use of fertilizers and nitrogen, and increasing seawater intrusion in coastal zones;
- (iii) Where will all these problems be occurring? Increasing droughts or floods are observed in some areas and have been projected through modelling - these projections need to be incorporated and summarized in the assessment;
- (iv) Which international groundwater systems are likely to prevent, buffer or mitigate water-related problems under increasing stresses during the coming decades?

Box 1: Some groundwater-related definitions[9]

(a) 'Aquifer' means a permeable water-bearing geological formation underlain by a less permeable layer, with the water contained in the saturated zone of the formation;

(b) 'Aquifer system' means a series of two or more aquifers that are hydraulically connected[10] ;

(c) 'Transboundary aquifer' and 'transboundary aquifer system' mean, respectively, an aquifer or aquifer system, parts of which are situated in different States;

(d) 'Aquifer State' means a State in whose territory any part of a transboundary aquifer or aquifer system is situated;

(e) 'Utilization of transboundary aquifers or aquifer systems' includes extraction of water, heat and minerals, and storage and disposal of any substance;

(f) 'Recharging aquifer' means an aquifer that receives a non-negligible amount of contemporary water recharge;

(g) 'Recharge zone' means the zone that contributes water to an aquifer, consisting of the catchment area of rainfall water and the area where such water flows to an aquifer by runoff on the ground and infiltration through soil[11];

(h) 'Discharge zone' means the zone where water originating from an aquifer flows to its outlets, such as a watercourse, a lake, an oasis, a wetland or an ocean;

(i) 'Coastal aquifer': means an aquifer located at the coast, usually hydraulically connected to the adjoining Large Marine Ecosystem;

(j) 'Virgin recharge' or 'natural recharge': means recharge or replenishment of 'natural' origin (rainfall, runoff, seepage from rivers or lakes, etc.), not significantly affected by human activity (artificial or induced recharge; return flows or other replenishment by used water; surfacing of terrains, etc.)

The TWAP Assessment was originally conceived to be carried out at two levels:

Level 1 includes a baseline global assessment and provides for periodic follow up monitoring of trends and impacts achieved from GEF and other interventions, applying simple and feasible[12] indicators. It also includes a tentative projection of key conditions and concerns over the next few decades. This part of the assessment is funded by GEF. Level 2 activities consist of a more detailed assessment of a few selected pilot systems, as an example of the level of aquifer knowledge necessary for management purposes.

Because of resource constraints, GEF then decided to limit the scope of the TWAP full-sized project to Level 1 only.

The Level 2 assessment is currently being carried out by UNESCO IHP with the financial assistance of the Swiss Agency for Development and Cooperation (SDC) in three transboundary aquifers: the Pretashkent (Central Asia), the Stampriet (Southern Africa) and the Trifinio (Central America) (UNESCO-IHP, 2015). This Level 2 assessment has also in particular dedicated a full component to gender issues with a dedicated approach.

The main products of TWAP Groundwater are listed in Table 1.1.

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[9] (a) to (h) are the definitions adopted by the UNGA Resolution A/RES/63/124 on the "Law of Transboundary Aquifers and the Draft Articles contained therein", 2008.

[10] Another possible definition is: "Aquifer system means an aquifer or a complex of hydraulically interconnected aquifers". This definition is consistent with the ubiquitous practice to use 'aquifer system' as well for indicating one single aquifer only.

[11] Another possible definition is "Zone where significant recharge (= replenishment) of the aquifer's groundwater is taking place, from whatever source of water".

[12] Feasible means that the data required to calculate the indicators are either readily available or can be collected in the framework of the GEF TWAP Full Size Project.

Table 1.1. Products of TWAP Groundwater component

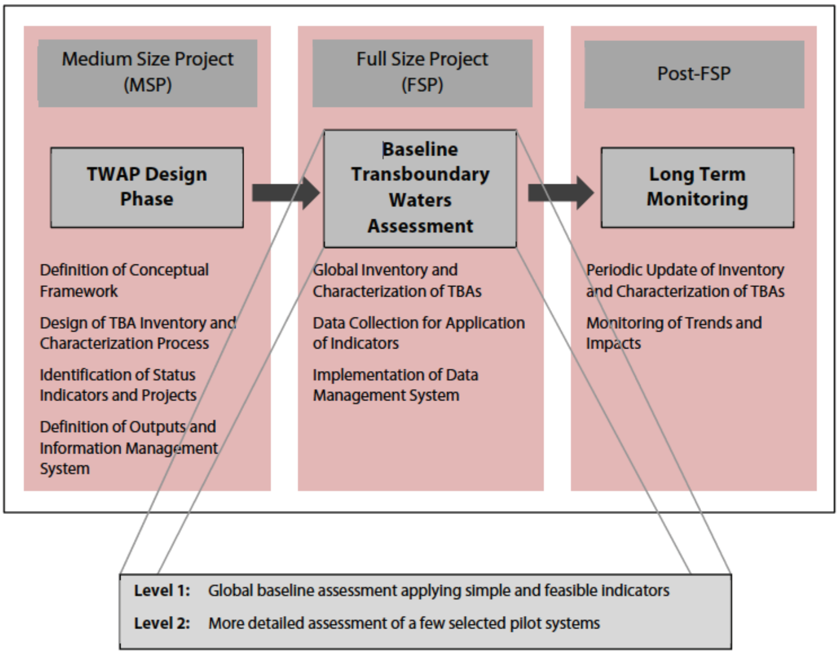
Outputs	Coordinates
Transboundary Aquifers Assessment Methodology (2012)	www.twap.isarm.org
Questionnaire Template	www.twap.isarm.org
Template for Transboundary Aquifer Information Sheets	www.twap.isarm.org
WaterGAP - Global-scale modelling and quantification of indicators for assessing transboundary aquifers – Final Report	www.twap.isarm.org
Assessment of SIDS Groundwater Systems - Final Report	www.twap.isarm.org
Transboundary Aquifer Information sheets (197)	http://twapviewer.un-igrac.org
SIDS Hydrogeological Profiles	http://twapviewer.un-igrac.org
SIDS Variables Values; SIDS references	www.twap.isarm.org
TWAP Groundwater Information Management System	**http://twapviewer.un-igrac.org**
Transboundary Aquifers and Groundwater Systems of Small Island Developing States: Status and Trends – Final Report	**www.twap.isarm.org**

1.2. Project architecture

The Transboundary aquifers component of TWAP can be divided into three different phases: design, assessment and monitoring. This overall architecture and its different phases is shown in Figure 1.1.

The methodology and execution arrangements for the TWAP Groundwater component were developed in the GEF funded medium sized project (TWAP MSP). This resulted in the report Methodology for the GEF Transboundary Waters Assessment Programme, Volume 2 (UNESCO-IHP, 2011). The methodology and execution arrangements were somewhat modified in the project preparation grant phase (PPG-phase), resulting in an updated report: UNESCO-IHP, IGRAC, WWAP (2012).

Figure 1.1. Overall architecture of the TWAP Groundwater Component.

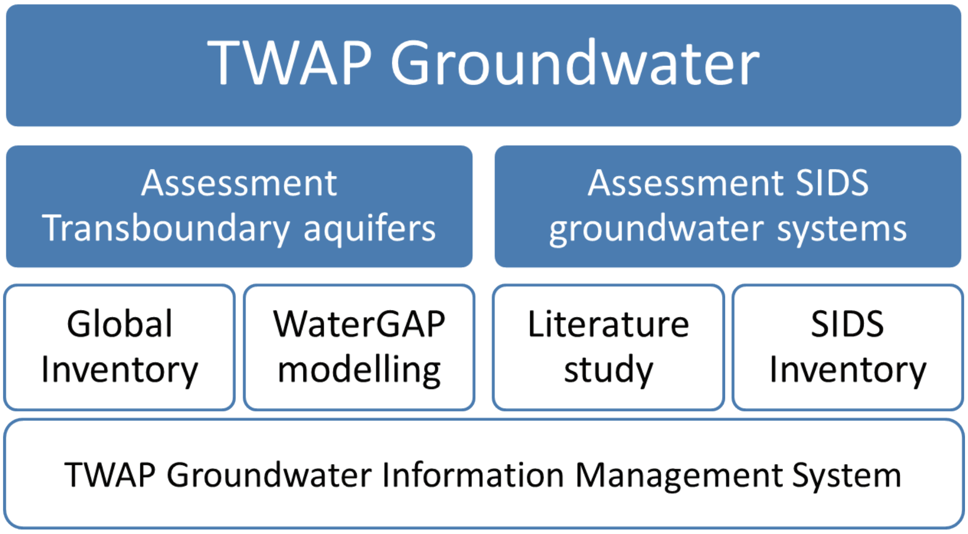


The current Full Size Project (FSP), which started in the beginning of 2013, comprises the Baseline Assessment. Before TWAP, no structured, global databases on transboundary aquifers or the groundwater systems of Small Island Developing States (SIDS) existed. A major effort was therefore made to collect the data to compile a structured database. The FSP can be divided into three subcomponents:

- Assessment of TBAs (TBA subcomponent), on the basis of data from a global inventory through questionnaires and scenario analyses using a global model (WaterGAP);
- Assessment of the groundwater systems of SIDS (SIDS subcomponent), on the basis of a literature study of peer-reviewed material, complemented by an inventory using questionnaires;
- Information management, including the construction of the first ever structured database with global data on TBAs and SIDS groundwater systems. The database can be accessed via a map-based web portal: the TWAP Groundwater Information Management System (IMS).

Figure 1.2 shows a graphical presentation of the different subcomponents of the FSP. 1.2.1.

Figure 1.2. Architecture of the Groundwater Component.



1.2.1. Assessment of transboundary aquifers

Data for the assessment of transboundary aquifers come from two different sources:

Global Inventory

This involved acquisition of data using networks of national experts (see section 1.3). Questionnaires were used to collect data and information in a structured way. The data collected include mapping of the boundaries of the transboundary aquifers and whenever possible an indicative cross-section of each transboundary aquifer. Regional workshops with national experts were held to discuss these data. The inventory unlocked much information from 'grey' literature and expert knowledge, which was previously only available at the national level. In general, indicators have been obtained for national country segment (TBA country unit), with harmonization discussed during the regional workshops.

WaterGAP model

Computation for TBAs >20 000 km^2 of the values of a subset of the TWAP Groundwater core indicators (see UNESCO-IHP et al., 2012), and of projections to 2030 – 2050, through modelling. Results can be displayed by model grid cell, whole TBA, or country segment.

All data from the global inventory and WaterGAP modelling are stored in the TWAP Groundwater data base and a standardized description for each transboundary aquifer has been compiled considering hydrogeological, socio-economic, environmental and legal and institutional (governance) aspects (see Table 1.1 and IGRAC, 2015).

The combined and integrated data from the Global Inventory and WaterGAP model are the bases for the indicator-based assessment of the transboundary aquifers describing the current state and also including scenarios for 2030 and 2050.

1.2.2. Assessment of the groundwater systems of SIDS

A two-step approach was used:

- Preliminary data collection: data were sourced initially from easily accessible global and regional publications and existing (and accessible) databases as recommended in the TWAP TBA Methodology (UNESCO-IHP et al., 2012). The same global data sources were used, if possible, for acquiring population statistics, climate data and climate projections, and geo-referenced data like island boundaries, digital elevation models.
- SIDS questionnaires survey: information provided by experts through questionnaires was integrated with the preliminary assessment data.

For the SIDS, standardized information sheets were compiled which include a map, cross-sections and basic information on the groundwater resources of the island (similar to the TBA information sheets).
For the SIDS subcomponent it was not possible to make use of a global model, as the islands are too small. Therefore the assessment of the SIDS contains no scenario analyses for 2030 and 2050.

1.2.3. Information management.

A major element in the TWAP Groundwater Component is information management. To facilitate storage, retrieval and visualization of results and underlying data, a dedicated Information Management System (IMS) has been developed. Final results and underlying data from the TBA and SIDS subcomponent have been uploaded to the IMS database. These data can be visualized as maps in the IMS-viewer. Results and underlying data can be downloaded in Excel format. The TBA and SIDS information sheets are also available for download (pdf-format). The IMS and its underlying database will facilitate the post-FSP activities, periodic update of inventory and characterization as well as monitoring of trends and impacts.

1.3. Project partners

UNESCO-IHP, in its capacity as lead agency for the TWAP Transboundary Aquifer and Groundwater component, established a partnership of experts and organizations at the national, regional and global level, committed to:

(i) Carry out the GEF-funded TWAP baseline assessment, adopting the methodology and modalities defined as a result of the TWAP design phase;
(ii) Explore options for long-term periodic follow-up assessments and monitoring with non- GEF resources in order to ensure the sustainability of TWAP's Groundwater component.

The partnership includes three categories of partners on the basis of their specific roles and functions:

1. The Core Group, formed by UNESCO IHP and IGRAC, along with the global network of UNESCO water-related centres and chairs. The core group had a central role in guiding and coordinating the TWAP groundwater assessment. Consisting of major players in the field of transboundary groundwater resource assessment and management globally, the core group had overall responsibility for and directly performed parts of the assessment. Calling on a wide array of ongoing cooperation and joint activities with many partners, the core group provided the main pillars of the TWAP assessment through programmes such as the Internationally Shared Aquifer Resources Management (ISARM) Initiative, the World-wide Hydrogeological Mapping and

Assessment Programme (WHYMAP), the United Nations World Water Assessment Programme (WWAP), high-resolution global data sets on soils, land use and irrigation from FAO's AQUASTAT and other related programs, and IGRAC's Global Groundwater Information System (GGIS) as well as the Global Groundwater Monitoring Network.

2. Regional Coordinators and Expert Networks. Regional partners have contributed to the assessment, with regional coordination mechanisms already in place, and provide the direct link to the countries. They have been responsible for organizing the acquisition of data on TBAs through existing (ISARM Americas) or newly-established regional expert networks. They also served as data providers, having access to existing data and local information systems. In a few cases the management of Regional Coordination and Expert Networks and the promotion of country involvement was entrusted to Regional Organizations (UNESCWA, and the OSS).
3. Key providers of expertise. This group of partners includes: Goethe University, Frankfurt, which had a central role in the modelling of selected core indicators for larger TBAs, including projections to 2030 and 2050 aimed at ensuring global coverage with harmonized data, and Simon Fraser University, Canada, which carried out the assessment of groundwater systems in SIDS, following the methodology defined by UNESCO IHP. In addition, hydrogeological, environmental, socio-economic, legal and institutional expertise was provided by UNESCO IHP senior advisors.

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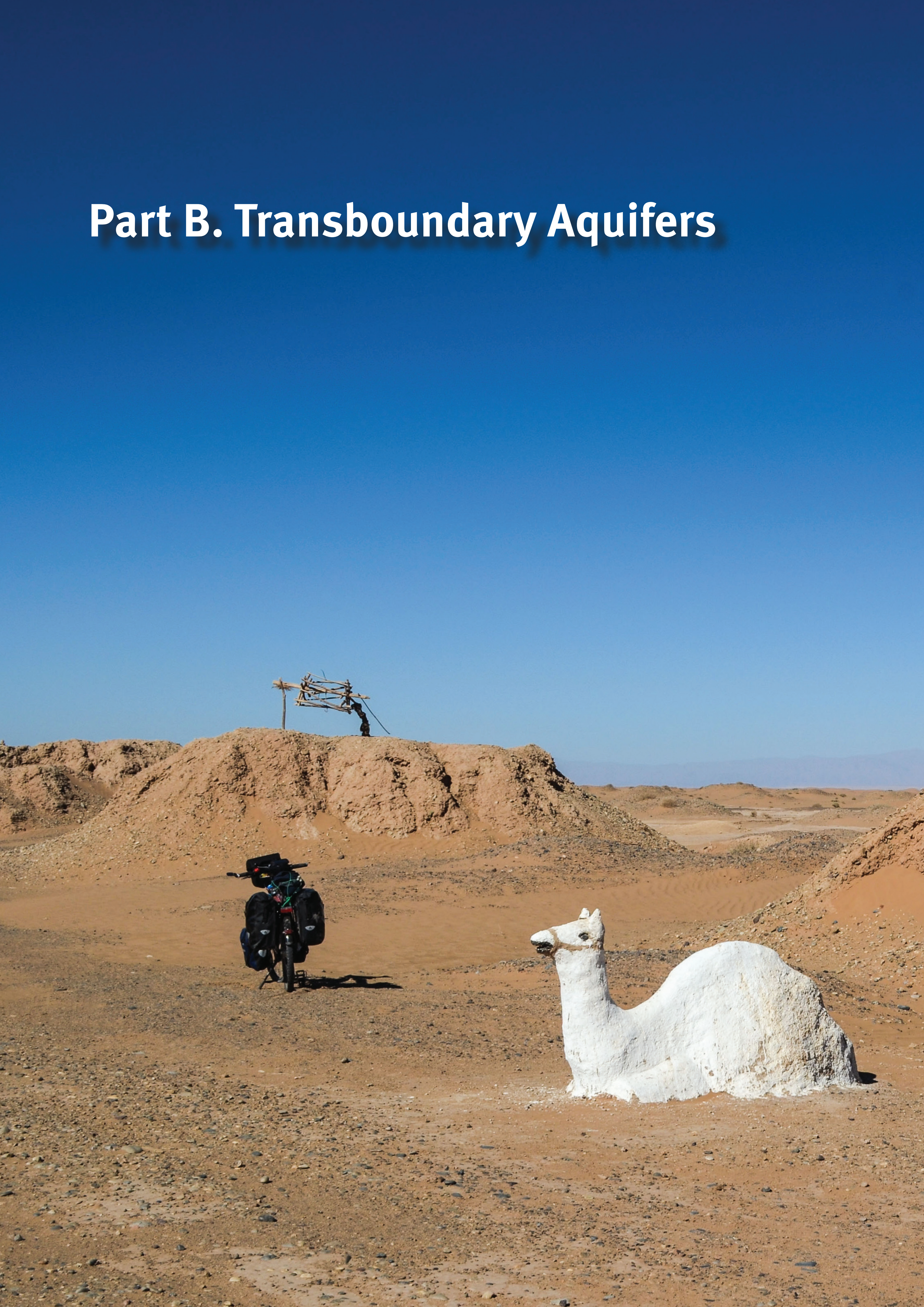
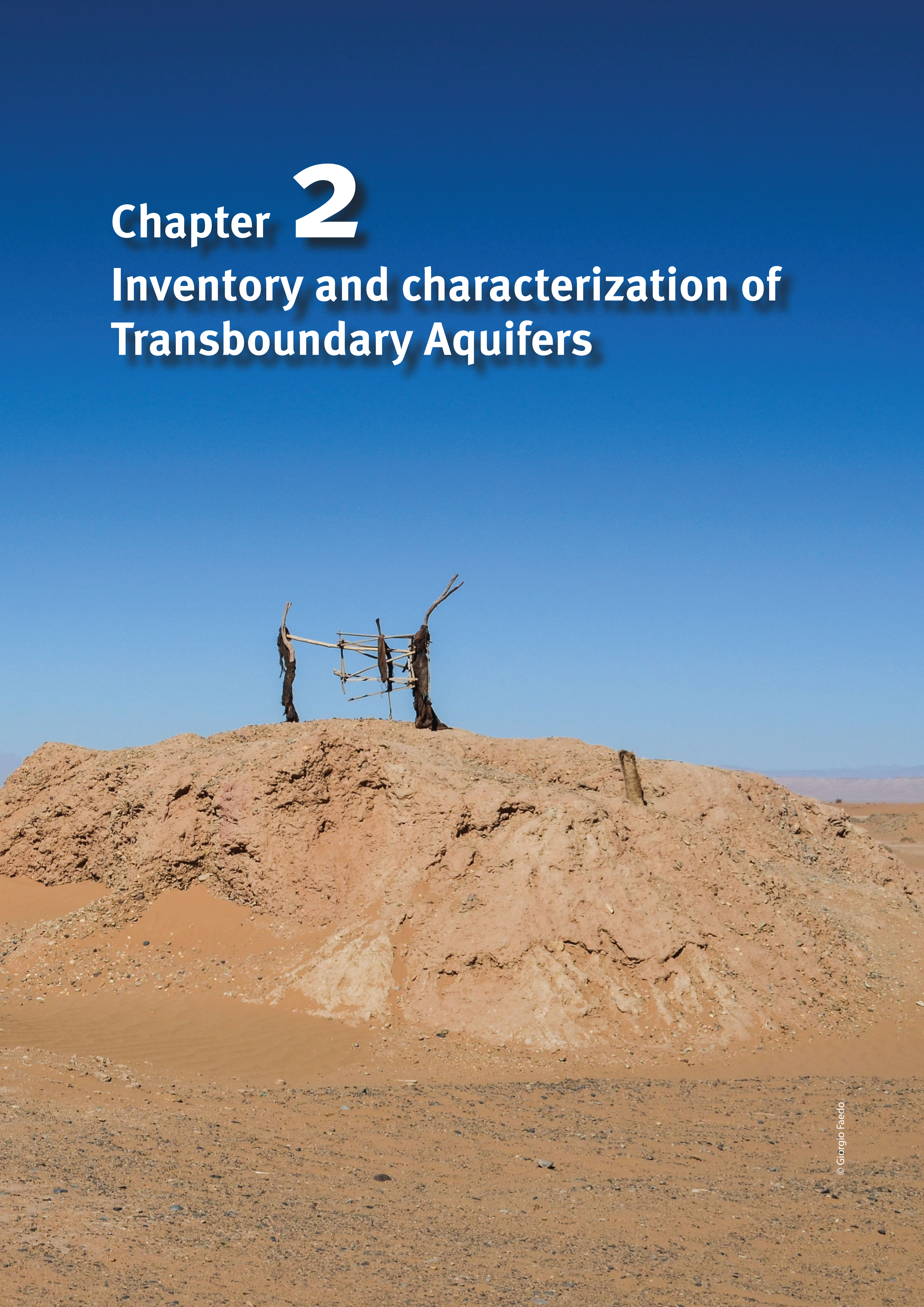
Part B. Transboundary Aquifers



Chapter 2

Inventory and characterization of Transboundary Aquifers



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Chapter Citation: Merla, A., Nijsten, G.J., del Val Alonso, L., Döll, P., Riedel, C., Dumont, A., Aureli, A. (2016). Chapter 2: Inventory and characterization of Transboundary Aquifers. In UNESCO-IHP and UNEP (2016). Transboundary Aquifers and Groundwater Systems of Small Island Developing States: Status and Trends. United Nations Environment Programme, Nairobi, pp. 11–41.

2. Inventory and characterization of Transboundary Aquifers

Unlike all other water bodies, aquifers are located in the subsurface and visible only through the eyes of science – hydrogeology. As a consequence, groundwater resource boundaries, or aquifer boundaries, are often very poorly known and many aquifers remain unknown or only partly recognized as separate, often unconnected, entities. This is particularly true for transboundary aquifers, which are often not recognized as shared resources by countries because of differing geological lithostratigraphic approaches, lack of communication between countries, uneven availability of data, or sovereignty issues. Lack of recognition of the nature of shared resources increases their vulnerability to anthropogenic pressures. Hence the need for a systematic effort to identify aquifers which are transboundary, facilitate the recognition of their transboundary nature by countries sharing the resource (inventory), and provide a somewhat standardized description of their main characteristics in terms of hydrogeology, environmental role and implications, socio-economic value and present governance structure (characterization).

2.1. Data acquisition methods

Prior to TWAP, no structured global databases on groundwater or transboundary aquifers existed. For the characterisation and assessment of the transboundary aquifers of the world two distinctly different sources of information were used:

- The Global Inventory, embracing all aquifers with surface extension greater than 5 000 km^2, which entailed data collection through questionnaires;
- Global Modelling, using the WaterGAP model, covering all TBAs with surface extension greater than 20 000 km^2.

2.1.1. The Global inventory

The People Network

A global inventory was conducted to establish the first structured and global database on transboundary aquifers. Data were collected by means of questionnaires (see below) and through the involvement of a large network of national experts. In doing so, TWAP Groundwater built on the network and experiences of ISARM . For the purpose of data collection, a regional approach was adopted, also following, as far as possible, the regional subdivisions used for ISARM[13]. Figure 2.1 gives an overview of the TWAP Groundwater regions.

UNESCO and IGRAC, with assistance from Regional Economic Commissions, established contacts with key national experts in the countries sharing TWAP transboundary aquifers. National experts were government officials, from academia, or in some cases consultants. In many countries the contributions to TWAP Groundwater data were provided not by one expert but by a team of experts. The list of the contributing experts as well as the regional coordinators can be accessed through the online portal: twap.isarm.org[14].

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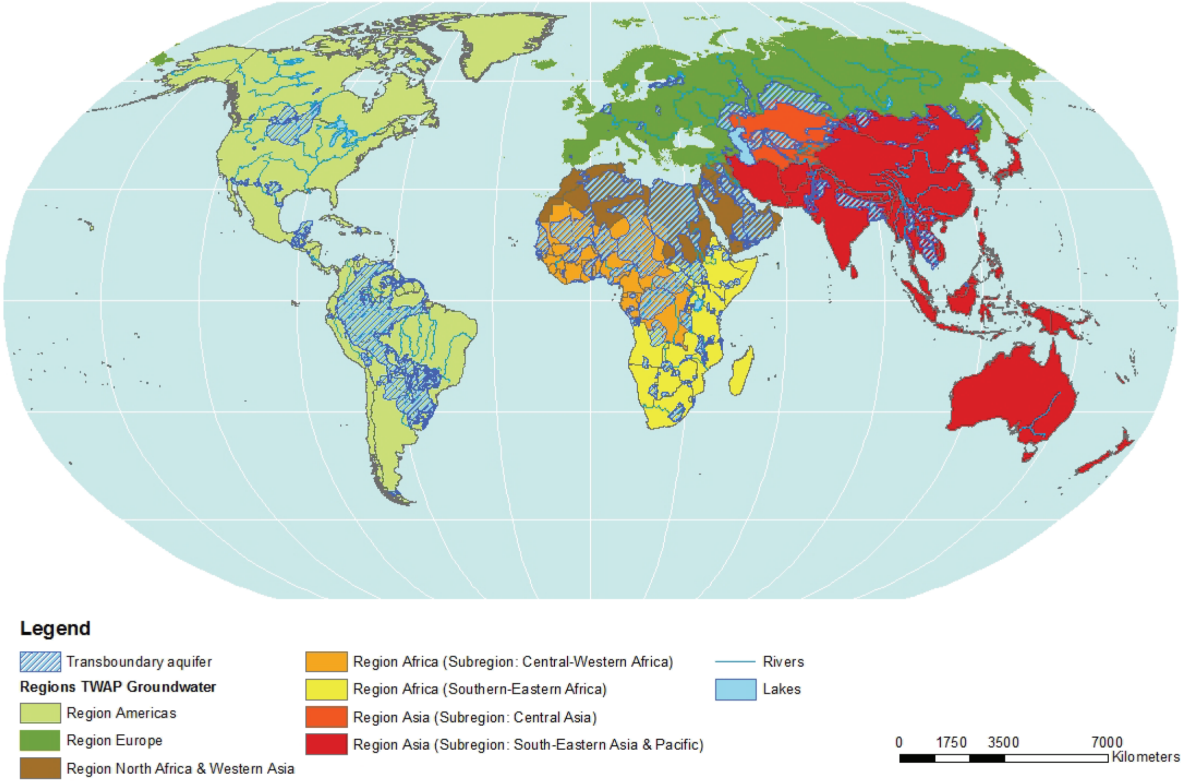
[13] The worldwide Internationally Shared Aquifer Resources Management (ISARM) Initiative is multi-agency effort, led by UNESCO-IHP and the International Association of Hydrogeologists (IAH) and aims to improve the understanding of scientific, socio-economic, legal, institutional and environmental issues related to the management of transboundary aquifers. See www.isarm.org for more information.

[14] The online appendix "TWAP Groundwater Contributors: Regional and National Experts" lists all the national experts who filled out their names in the questionnaires. This list may not be complete, since the names and contact details of the national experts had not been filled out for some questionnaires.

Figure 2.1. Map showing regions used for Global Inventory.



A regional coordinator was appointed for each region. The regional coordinators were the liaisons between the national experts and the UNESCO IHP/IGRAC team. Their role included distributing relevant information (like the questionnaires) to national experts, assisting national experts with questions they had, and collecting the data and information from the national experts. Regional experts themselves also contributed to the data collection by bringing in their knowledge of the region and filling some of the data gaps. Once national experts had provided data and information, the regional coordinators were responsible for checking the quality and consistency of these data and compiling all information into regional reports, which provided the basis for this TWAP main report and assessment. Figure 2.2 provides a schematic overview of data acquisition in the Global Inventory.

Regional workshops were organised for most regions (Table 2.1). Their aims were:

- to create or re-enforce regional networks for cooperation on TBA assessment and management by bringing national experts together;
- to inform national experts of the background, purpose and methodology of the TWAP and in particular of TWAP Groundwater;
- to exchange preliminary data on the TWAP TBAs between national experts. In the workshops, national experts worked intensively with experts from neighbouring countries. One of the major outcomes of the regional workshops was the improved delineations of many TBAs.

No regional workshops were held for North Africa and Western Asia, or for Western Europe. For North Africa and Western Asia, data were provided not by national experts but by regional organisations and regional experts. This was because detailed studies had been done in recent years for many of the aquifers in the region, and these studies could be used for TWAP, such as UN-ESCWA and BGR (2013).

Figure 2.2. Schematic overview of data acquisition in Global Inventory.

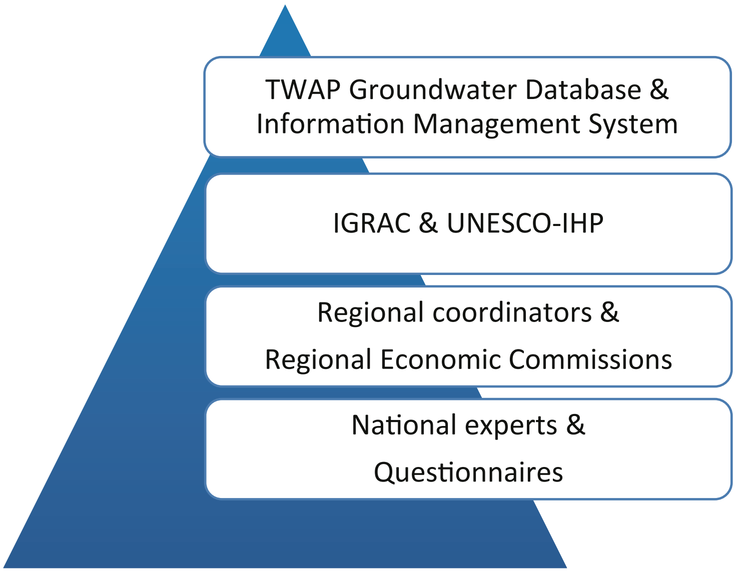


Table 2.1. Overview of TWAP Groundwater meetings and regional workshop

TWAP Groundwater Inception meeting[1]	All regions	Italy - Perugia	14-15 May 2013
Introductory regional meeting[2]	Europe	Germany - Berlin	21 August 2013
Regional coordinators meeting[3]	All regions	Netherlands - Delft	16-17 October 2013
Regional workshop	Americas (North, Central and South)	Uruguay – Montevideo	9-11 December 2013
Regional workshop	Southern and Eastern Africa	Kenya – Nairobi	4-6 March 2014
Regional workshop	West and Central Africa	Senegal – Dakar	22-24 July 2014
Regional workshop	Central, South, South East and East Asia	Thailand - Bangkok	7-9 October 2014

[1]: The inception workshop was organised to inform all project partners about the Groundwater component of TWAP and to discuss project execution arrangements.
[2]: In this meeting the approach for western Europe was discussed and agreed, as this approach was slightly different from the rest of the world (see text).
[3]: A meeting for regional coordinators was organised to inform them in detail about the project and execution arrangements. This meeting was also used to test the TWAP Groundwater Questionnaire..

For Western Europe the situation was different. No TBAs have been defined in most countries in the EU. This is a direct result from the Water Framework Directive in which Groundwater Bodies are used as a unit for groundwater management and reporting, rather than (transboundary) aquifers. Groundwater bodies are mostly defined by administrative rather than by hydrogeological boundaries, and as a consequence transboundary aquifers have not been mapped in many parts of Europe. An introductory regional meeting was held to discuss how to deal with this situation and it was decided to include a small number of European TBAs in TWAP. In total 9 TBAs for Europe were delineated and assessed.

To summarise, the approach with data collection by national experts has allowed better capture of existing knowledge and expertise, and creation of partnerships with regional organizations and networks. Country involvement was essential to improve data availability, and to achieve visibility of the aquifers and mutual recognition of their shared nature.

Data acquisition was a complex activity because it encompassed a large number of aquifer systems, spread over almost all countries of the world. Conditions ranged from well-documented aquifer systems managed by institutions that monitor all relevant aspects (only a few TBAs) to poorly explored aquifer systems that are not monitored or managed at all (the majority of TBAs).

TWAP Groundwater questionnaires

Following the positive experience from ISARM Americas, questionnaires were used as a way to organize, in a structured way, the acquisition of new data and information directly from countries and regions to complement the scarce already-available information. Questionnaires were directed to country and regional experts, strengthening country/local participation and ownership. Responses were the responsibility of regional coordinators, who coordinated country inputs, performed quality checks on the questionnaires submitted by national experts and complemented them whenever possible, for example through regional geological considerations and expertise[15].

The TWAP Groundwater questionnaire (Figure 2.3) was developed by IGRAC and closely follows the data needs described in the revised TWAP Groundwater Methodology (UNESCO-IHP et al., 2012, see Table 1.1).

The questionnaire was set-up in Microsoft Excel format which allowed IGRAC to build in some simple automatic checks of answers, for example to make sure that maximum aquifer thickness > average > minimum thickness, and also made it possible to extract compact data submission forms which could be uploaded directly into the TWAP Groundwater database (see section 2.2.5).

Figure 2.3. Impression of TWAP Groundwater data collection questionnaire and user guide.

Transboundary Water Assessment Programme (TWAP)
Groundwater component
Digital Questionnaire for Data Collection

Version: 2.2_UK_ALL

TWAP Groundwater
- Digital Questionnaire for Data Collection -

2. Personal Details

TWAP National Coordinator:

Given name(s):
Surname:

7.2. Groundwater pollution [ESSENTIAL]

Pollution is considered any aspect of water quality (chemical, biological, thermal) which is caused by people and which interferes with the intended use of the groundwater. Here we assess pollution by defining the zones with groundwater pollution in the aquifer area. This can be zones with pollution from point sources (e.g. industrial spills) or zones which suffer from diffuse pollution (for example from agriculture practices).

7.2.1.Choose the option that better represents the groundwater quality in your national segment of the aquifer:

☐ 1. No pollution has been identified
☐ 2. Some pollution has been identified / suspected but areal extend not expecified
☐ 3. Significant pollution has been identified

7.2.2. If pollution is significant and sufficient data are available, please specify the estimated % of the aquifer's area that is affected by pollution:

7.2.3. If significant pollution has been identified, please, specify to what depth is groundwater affected:

☐ 1. Only superficial layers
☐ 2. Significant part of the aquifer
☐ 3. The whole thickness of the aquifer

7.2.4. Indicate the most important sources of groudwater pollution in the aquifer [more than one answer is possible]:

☐ 1. Landfills/waste disposal sites
☐ 2. Households
☐ 3. Municipalities
☐ 4. Industrial waste disposal
☐ 5. Military sites
☐ 6. Agricultural practices (irrigation, pesticides, fertilizers)
☐ 7. Mining activities
☐ 8. Oil/gas production and transport activities
☐ 9. Leakage through boreholes
☐ 10. Unknown

7.2.5. Indicate the most important pollutants affecting aquifers groundwater quality [more than one answer is possible]:

☐ 1. Salinisation
☐ 2. Nitrogen species
☐ 3. Hydrocarbons
☐ 4. Pathogens
☐ 5. Pesticides
☐ 6. Heavy metals
☐ 7. Industrial organic compounds
☐ 8. Termal pollution
☐ 9. Unknown

7.2.6. Choose methodological approach you have used to reach that value:

<choose from list>

7.2.7. Are major polluted zones located in a map and is the map attached to this questionaire?

<choose from list>	<automatic based on answer>

7.2.8. Choose already entered reference from *User References list or first* click here to enter new reference

<choose from list>	<choose from list>	<choose from list>

7.2.9. Check this box if there is no information/knowledge available to answer this question or any of the sub-questions ☐

TWAP_DataCollectionForm_2.2_UK_ALL 18/02/2014 7. Environmental aspects | 19

Transboundary Water Assessment Programme (TWAP)
Transboundary Aquifers component

DIGITAL QUESTIONNAIRE
FOR DATA COLLECTION
- USER GUIDE -

- option 1) Enter your literature directly in worksheet *3. References* at the beginning of the questionnaire.
- option 2) , Enter your literature references one by one while working your way through the questions in the different worksheets by selecting [*Click here to enter new reference*]. This will take you back to worksheet *3. References* where you can enter the literature reference.

To indicate which references have been used to answer a specific question you can simply select it from the pull down menus marked as < choose from list >. See figure below.

Click here to select reference

What graphic information can I provide and how do I submit this information?

Please read carefully the information provided below and follow the guidelines to produce the (optional) maps and cross-sections. We would like you to send all graphic information via e-mail to your Regional Coordinator and to IGRAC (e-mail address provided below).

One of the outputs from the project will be 'Information briefs per Transboundary Aquifer and SIDS aquifer' (TBA-briefs in short). These TBA-briefs will not only contain tabular data but we're also aiming to include information that will help to visualise the groundwater resource, such as (sketch) maps showing main hydrogeological aspects and schematic hydrogeological cross-sections.

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[15] See the online appendix "TWAP Groundwater Contributors: Regional and National Experts" (twap.isarm.org) for a list of all experts that contributed to this activity.

National experts received the digital questionnaires, a concise user guide, and a set of maps showing the location, name, identification code and boundary of the TBAs for each aquifer in the region, as they were known prior to TWAP. These data were sourced from the map of Transboundary Aquifers of the World, Update 2012 (IGRAC, 2012) supplemented by data recent studies like UN-ESCWA and BGR (2013). Questionnaires were made available in English, French, Russian and Spanish. National experts were asked to provide information for the segment of the transboundary aquifer in their country, and one questionnaire was supposed to be filled out for each country segment of each TBA.

A pdf-version of the English questionnaire, the explanatory guide, and the original version of the questionnaire (MS Excel-version) is available for download from the project website (see Table 1.1)

The TWAP Groundwater questionnaire consists of 11 sections. It starts with a brief introduction toTWAP and some important notes for filling out the questionnaire. Section 2 captures the contact details of the national experts contributing to the questionnaire, section 3 provided space to list all references, which were used to fill out the questionnaires. In section 4 the experts are asked to provide administrative information about the transboundary aquifer such as its name and the countries sharing it. Section 5 describes the geometry, formation and hydraulic properties of the aquifer, starting with the delineation of the aquifer boundary. Using the provided maps as a starting point, experts were invited to provide improved information if available. Sections 6 to 9 ask for data related to hydrogeological aspects such as recharge and groundwater depletion; environmental aspects such as groundwater quality and pollution, socio-economic aspects (like groundwater abstraction volumes and type of use), and legal and institutional aspects such as existing agreements and measures to control groundwater abstraction and protection. Section 10 relates to additional information like cross-sections of the aquifer and map information, such as an improved map of the aquifer boundaries or a map indicating the locations of recharge zones, zones of major abstraction, pollution, etc. This visual information is very important for creating a better understanding of the three- dimensional conceptual model of the TBAs. Section 11 provides the national expert with an overview of the percentage of completion of the questionnaire and enables the data provided to be saved in a data submission form. This small file is easy to send by e-mail and can be directly uploaded into the TWAP Groundwater Database (see section 2.2.5).

Sections 6 to 9 of the questionnaire are divided into sub-sections. The top sections are called ‘key variables and parameters’, the lower sections are called ‘optional variables and parameters’. The key variables are needed to calculate the ten core indicators, the optional variables and parameters provide input to the ten additional indicators (see section 2.2.4 on indicators).

2.1.2. WaterGAP global modelling (for TBAs > 20 000 km^2)

- In addition to collecting data using questionnaires in the global survey, a global water use model was used to generate information on the groundwater resources in the large TBAs (larger than 20 000 km^2). WaterGAP (Water - Global Assessment and Prognosis) is a global hydrological and water use model to assess the human-freshwater system under historic and future climate conditions. It comprises the WaterGAP Hydrology Model (WGHM) and five water-use models for the irrigation, households, and manufacturing sectors and for cooling of thermal power plants. Covering the entire global land area except Antarctica on a 0.5° grid (55 km × 55 km at the equator), WGHM computes daily time-series of fast surface and subsurface runoff, groundwater recharge, and river discharge as well as storage variations of water in canopy, snow, soil, groundwater, lakes, reservoirs, wetlands, and rivers. Model inputs include time-series of climate data between 1901 and 2009 (such as precipitation, temperature and solar radiation) and physiogeographic information such as land cover, soil type, relief, and hydrogeology (See Table 1.1, WaterGAP - Global-scale modelling and quantification of indicators for assessing transboundary aquifers – Final Report). WaterGAP simulations were focused on transboundary aquifers larger than 20 000 km^2 because input data for the model are limited and have limited spatial resolution. Global-scale results provided with a 0.5° resolution can be used to derive information for smaller aquifers, although with very high uncertainty.

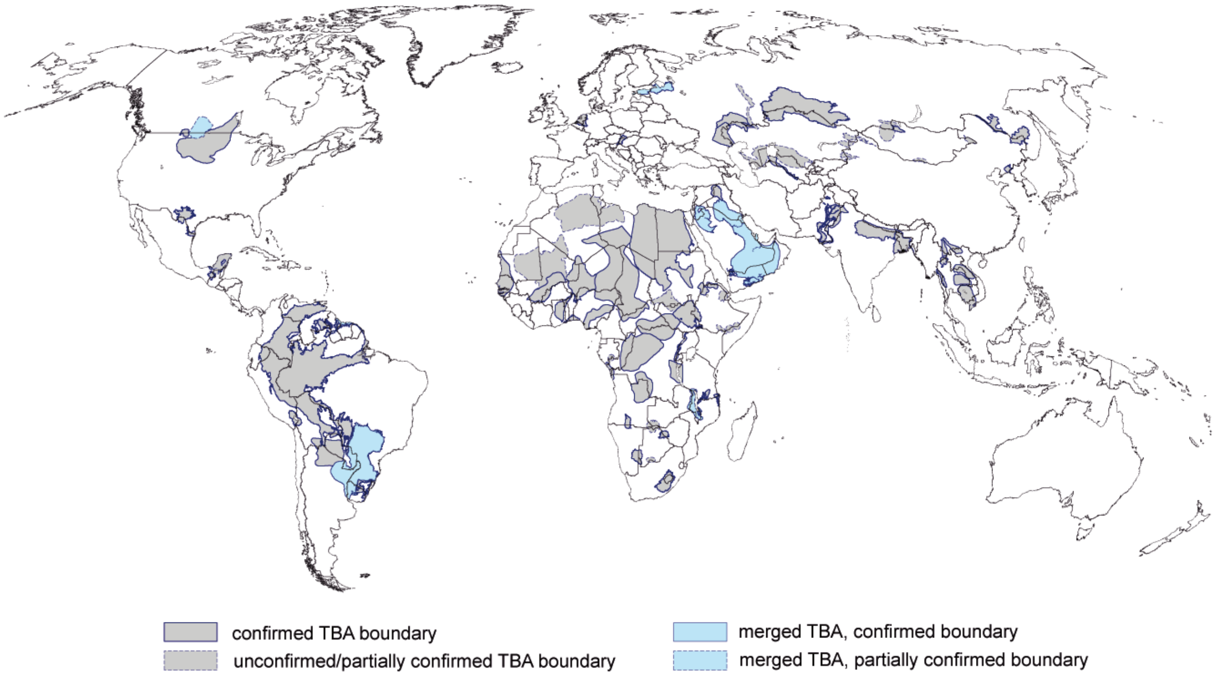
Effects of modelling assumptions in WaterGAP on computed indicators:

- Only one unconfined aquifer is modelled, meaning that indicators cannot be assigned to individual, three-dimensional aquifer bodies that may be overlaying. However, knowledge about shape and extent of TBAs is, in most cases, highly uncertain.
- Livestock water use is neglected in this study; an analysis of consumptive water use of livestock in 2010 showed that values of less than 1 mm/yr occur in most TBAs.
- Horizontal GW flow between cells as well as capillary rise is not taken into account. The effect of neglecting these processes on indicators 3.1 (groundwater depletion) and 4.2 (groundwater development stress), however, is considered to be small compared to uncertainties regarding estimated groundwater recharge and abstractions.

Merged aquifers:

105 TBAs larger than 20 000 km^2 were identified. Some of these lie on top of other aquifers, and WaterGAP, like other global-scale hydrological models, cannot compute the water balance of individual overlying aquifers. It assumes that there is one aquifer that receives all the groundwater recharge from the soil and surface water bodies above it and that all groundwater abstractions are taken from this aquifer. It was therefore necessary to merge overlying aquifers. 22 TBAs were merged into 8 TBAs because of large overlaps resulting in 91 TBAs as a basis for the WaterGAP assessment (see Figure 2.4, and Appendix 1).

Figure 2.4. TBAs (>20 000 km^2) included on the Water GAP assessment. Merged TBAs are shown in blue.



2.2. Main Outputs

The outputs were:

- TWAP Groundwater Database (section 2.2.1)
- Transboundary Aquifer Information sheets (section 2.2.2)
- TWAP Groundwater Indicators (section 2.2.4)
- TWAP Groundwater Information Management System (section 2.2.5)

2.2.1. TWAP Groundwater Database

The global survey with questionnaires filled in by national and regional experts and information obtained from regional workshops has provided wealth of information. The merits of the TWAP Groundwater Survey have been threefold: the global survey reinforced existing networks and helped build new networks of experts working on transboundary groundwater resources; the global survey unlocked a significant amount of data and information which was previously only available at the national or even local level, often in the form of grey literature or expert knowledge; and in making use of questionnaires the data have been collected in a structured and harmonised way, which has made it possible to set up the first comprehensive global database on transboundary groundwater / aquifers.

Drawing on knowledge and expertise at the regional and country levels was indispensable for:

- Expanding the inventory of TBAs > 5 000 km² with new entries;
- Obtaining a definition of TBA boundaries (before TWAP only available for a limited number), to allow the application of the WaterGAP model (computation of groundwater quantity and socio-economic indicators and projections);
- Collecting information for the computation of quality, ecosystems and governance indicators.

Prior to TWAP, 166 transboundary aquifers larger than 5 000 km² were known to exist and the locations of the aquifer boundaries were known for only a portion of them. Thanks to TWAP, more transboundary aquifers have been added (also 27 TBAs smaller than 5 000 km²) and for many existing aquifers the location of the aquifer boundary has been much improved. Also some transboundary aquifers were removed from the list as national experts no longer considered these units to be transboundary because of the limited horizontal hydraulic continuity, or because existing aquifers were merged into newly defined aquifers based on more recent insights. The final list of transboundary aquifers included in the TWAP assessment covers 199 transboundary aquifers. Section 2.3.1 – ‘Delineation of aquifer boundaries’ describes in more detail the achievements of TWAP in terms of aquifer numbers and delineation of boundaries.

The results from TWAP Groundwater are based on a combination of pre-existing information (e.g.: ISARM atlas), newly acquired information (questionnaires/regional networks) and regional geological information, in situations where, in absence of specific information, regional geology suggested the likely presence of important aquifer systems.

Further, the Global Inventory clearly highlights, on a global scale, the data gaps in knowledge of TBAs. These data gaps represent situations where no research or structured data collection seems to have been done, or situations where some data may exist but are not accessible.

All data and information from the Global Inventory, as well as the results from the WaterGAP model simulations and the SIDS subcomponent, have been stored in a structured database which is maintained by IGRAC. This database represents the first Global Inventory and Database of Transboundary Aquifers and Groundwater systems of SIDS.

In order to make the data in the database available to a wide audience, a dedicated information management system has been developed. This TWAP Groundwater Information Management (TWAP Groundwater IMS) system allows anyone with internet access to view, analyse and download the data and information from TWAP in different formats. The TWAP Groundwater IMS can be accessed via: http://twapviewer.un-igrac.org. See section 2.2.5 – *TWAP Groundwater Information Management System* for further details.

As explained in section 2.1.1.2 – TWAP Groundwater questionnaire, the national experts were asked to provide references to literature they used to fill out the questionnaires. Together the national experts used more than 3 000 references. This list of references is too extensive to include in this report. It can be accessed via the TWAP groundwater website and TWAP Groundwater Information Management System (see Table 1.1).

2.2.2. Transboundary Aquifer Information Sheets

All data collected in the Global Inventory and the results from the WaterGAP modelling are available in the TWAP Groundwater Information Management System in the form of world maps showing the distribution indicator values and underlying data per transboundary aquifer and their national segments. The TWAP Groundwater IMS also contains a summary description of each TBA assessed in TWAP, following a standard format (see Table 1.1). These *Aquifer Briefs* or *Transboundary Aquifer Information Sheets* include:

- The aquifer code, a unique identifier and part of the essential information for the database;
- The aquifer name, which is often descriptive and is agreed by countries, with alternative names included where applicable;
- A summary of the key geographical and hydrogeological information, including the areal extent of the TBA, the countries sharing the aquifer, information on the climatic environment, and the key hydrogeological features of the aquifer;
- The standard delineation map , which includes the approximate TBA boundaries in relation to political boundaries and major geographical features (rivers, lakes, oceans, mountains);
- The hydrogeological cross-section, which provides a conceptual understanding of the third dimension of the TBA, and is included wherever this was provided by national experts;
- A table with the values of the ten core indicators (from WaterGAP and from the questionnaire data) used in the TBAs assessment to convey clear messages on the needs and relative priority for joint management of the TBA;
- A summary table of the key aquifer parameters that provide essential information for characterization of the aquifer;
- A standardized aquifer narrative description of the scientific information that reflects in a balanced way the multi-disciplinary approach of the TWAP methodology (hydrogeological, environmental, socio-economic, legal and institutional matters). This includes the important standard aspects of the aquifer geometry and the hydrogeological setting and its links to other water systems. The environmental aspects of the water quality and groundwater-dependent ecosystems are followed by the socio-economic aspects, which concentrate on the groundwater use relative to the total fresh water abstraction over the aquifer area. The legislative context and the institutional setting of the aquifer states are reviewed, together with other governance issues.
- The description is concluded with the identification of key issues of concern; note that at the level of the global comparative assessment of TWAP the selection and definition of emerging and priority issues and hotspots still involve a strong element of human perception and subjectivity.
- Any additional and relevant maps of interest are appended to the standard description where available.

Appendix 2 shows six examples of TBA Briefs.

2.2.3. Questionnaire responses: overview by continent or region

A total of 197[16] TBA information sheets were produced. The information output that was achieved in the different regions, and for different information elements, is summarized below. Appendix 3 contains diagrams showing statistics of the responses on the main TBA features (Appendix 3 Figures 1-8), and information elements of the aquifer description (Appendix 3 Figures 9-16).

The major advance achieved is that standard delineation maps have been produced and are available for every TBA. Cross-sections are only available for 27 per cent of TBAs. For Europe and Western Asia the availability of cross-sections is much better, more than 70 per cent.

Of the total 197 information sheets, information was received from all national segments for only 21 aquifers: five TBAs for the Americas, three for Central Asia, one for SE Asia, five for Europe, three for WC Africa, and four for SE Africa. Thus, in most cases, cumulative information for entire aquifers, e.g. aquifer annual recharge, annual abstraction and aquifer volume, has not been obtained. Important groundwater stress indicators, i.e. abstraction relative to mean annual groundwater recharge, as well as the human dependence on groundwater, cannot therefore be assessed satisfactorily on a transboundary aquifer basis using questionnaire data.

Equally important for comparative purposes are the indicators of TBA development and stress. The achievement was on average between 40-50 per cent for the two indicator groups (the difference between the two groups is not significant, because in both groups the information was not complete).

The aquifer description information enables a few main conclusions to be drawn:

- the descriptive information (aquifer geometry and lithology, links) generally had the highest response. Water quality and pollution also had a reasonable response;
- the ecological aspects, shallow groundwater/ occurrence of groundwater-dependent ecosystems, had a generally poor response;
- important, quantitative information was obtained for:
  - Annual aquifer recharge: 109 TBAs;
  - Annual groundwater abstraction: 115 TBAs;
  - Aquifer transmissivity: 119 TBAs;
- annual total fresh water abstraction was generally little known;
- important new information components are the bilateral and national institutional arrangements. These had a 50-90 per cent return for the different regions;
- the listing of priority issues of concern had a satisfactory level of response, and represents the conclusion of each TBA information sheet (brief). Lack of issues of concern is obviously also a conclusion. Only in 38 cases was no response given;
- Europe and Western Asia appear to have the most complete information returns.

2.2.4. TWAP Groundwater Indicators

The Global Inventory and the WaterGAP model simulations yielded large amounts of data on different parameters and variables. These data provide important information for further study, but it is not easy to create clear overviews of the current status of the transboundary aquifers or to monitor future changes from this large amount of information.

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[16] TWAP Groundwater considered 199 transboundary aquifers for which data have been provided. Data have been provided for the transboundary aquifers EU91, EU92 and EU93, but since these aquifers form a transboundary aquifer system, they are described in one transboundary aquifer information sheet.

In the preparation phase of TWAP Groundwater a set of indicators was therefore developed and defined to serve the following objectives:

(i) capture the current state and projected trends of transboundary groundwater resources globally, as a basis for continuing, long-term monitoring;

(ii) allow a comparative assessment of transboundary aquifers (TBAs), in a region or globally, in terms of various parameters (quantity, quality, etc.). These indicators and their integration into indices will in turn facilitate priority setting for GEF action and strategies;

(iii) monitor the evolution of these parameters over time, i.e. the status of transboundary aquifers, and hence provide an indication of the effectiveness of stress-reduction measures being implemented by the GEF and others.

Box 2. Variables, indicators, and indices

Parameters and variables: Quantities to which a value may be assigned on the basis of observation. Parameters are considered to be constant (on the human time scale) while variables may change in time because of factors like human impacts or climate variability.

Indicator: Usually, a combination of variables, intended to convey a message. The message follows from comparing the values of the variables in a normative framework enabling assignment of qualifications to the variable in a transparent way. Examples of indicators are: renewable water per capita, and groundwater abstraction as percentage of total abstraction.

Indices: Combinations of indicators calculated according to specific algorithms aimed at determining ranking positions. They are usually dimensionless. The relationship to the underlying observed variables is less transparent than for indicators.

Given the range of potential transboundary aquifer management issues, the following aspects were considered most relevant in the choice of indicators:

1. **Characteristics that define or constrain the value of aquifers and their potential functions:**
   Magnitude of the groundwater resources in terms of recharges and stored volume; water quality; accessibility (depth to groundwater and groundwater level); vulnerability with respect to pollution, or to climatic variation and climate change.
2. **Role and importance of groundwater for humans and the environment:**
   In particular reflected by quantities of groundwater exploited for different purposes (sectors).
3. **Changes in groundwater state:**
   Changes in stored volume and/or groundwater level (in particular depletion); changes in water quality (in particular by pollution).
4. **Most important area-specific drivers of change and pressures:**
   Demography (such as population density and growth, urbanization, migration); socio-economic development (such as changes in wealth, water use efficiency or water profitability, transition to economy with other water use intensity); groundwater development stress (=abstraction/recharge); presence of active pollution sources (emissions).
5. **Enabling environment for groundwater resource management interventions:**
   Presence and quality of legal and regulatory frameworks for groundwater management at domestic and TBA levels; presence and quality of institutions at domestic and TBA levels for developing groundwater management plans and implementing legal, regulatory, economic and other interventions; presence, nature and quality of monitoring networks.

The computation of TWAP groundwater indicators was based on:

1) The simulation results from the WaterGAP model for the 91 WaterGAP TBAs > 20 000km^2 (Figure 2.4)[17], for indicators related to quantity and socioeconomics, including the four projected indicators;
2) The results from the Global Inventory (questionnaire survey) for all TWAP TBAs. The questionnaires are the only basis for the computation of groundwater quality and governance indicators;
3) Existing globally-accessible databases that ensured coherence in the data sources across TWAP. This is the case, for example, in relation to climate and demographic data.

The TWAP Groundwater Current State and Projected Indicators (see Table 2.2), and the level of response and coverage achieved, are summarized in Table 2.3. This lists and specifies 20 indicators. Among these, two levels of priority have been indicated. Ten of the indicators are core indicators (Table 2.2). Relevance and expected feasibility were the main criteria for assigning the status of core indicator to these ten. The computation of the other ten indicators, additional indicators, – was possible only sporadically. In Table 2.3 indicators are grouped according to the TWAP Groundwater Methodology, adopting the DPSIR (Driving Forces-Pressures-State-Impacts-Responses) approach. See Table 2.2 for the correspondence with Thematic Clusters (Quantity, Quality, Socioeconomics, and Governance).

Table 2.2. Aquifer description items covered by the ten TWAP Groundwater core current state and projected indicators (the latter in bold characters). The indicator codes are in parentheses corresponding to the DSIR approach shown in Table 2.3.

Thematic Cluster	Core Indicators
Quantity	Recharge (1.1) Groundwater depletion (3.1)
Quality	Natural background quality (1.3) Groundwater pollution (3.2)
Socio-economic	**Population density (4.1)** **Renewable groundwater per capita (1.2)** **Human dependence on groundwater 2.1)** **Groundwater development stress (4.2**
Governance	Transboundary legal framework (5.1) Transboundary institutional framework (5.2

2.2.5. TWAP Groundwater Information Management System

Introduction

In order to make all data from TWAP Groundwater available to stakeholders and the wider public, a dedicated web-based data portal or information management system has been developed. The TWAP Groundwater Information Management System (IMS) gives access to all data in the TWAP Groundwater database, the Transboundary Aquifer Information Sheets and the SIDS Groundwater systems Information Sheets. The IMS contains aggregated data, variables and indicators, encompassing the hydrogeological, environmental, socio-economic and governance dimensions of the aquifer systems. The map viewer enables users to make comparisons between aquifers at the global or regional scale.

The TWAP Groundwater IMS has been integrated into the larger Global Groundwater Information System (GGIS) which is maintained by IGRAC. The benefits of this are twofold:

- GGIS contains a wealth of information on groundwater world-wide. By integrating the TWAP Groundwater IMS into the GGIS, this information is only a mouse-click away for users of the IMS.
- IGRAC's mission, as the Global Groundwater Centre, is to promote sharing of information and knowledge required for sustainable development, management, and governance of groundwater resources worldwide. IGRAC is dedicated to hosting and maintaining the TWAP Groundwater IMS for the long term, which guarantees sustainability of the system and facilitates future updates of the database.

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[17] There are 105 TBAs larger than 20 000 km^2, but in WaterGAP some TBAs have been merged (see Appendix 1).

Table 2.3. TWAP Groundwater Indicators.
Descriptions, classifications and availability in Global Inventory and WaterGAP

	Indicator	Priority[1]	Description	Unit	Classification used in TWAP Groundwater IMS	Current State[2]		Projected[3]
						G.I.[4]	W.G.[5]	W.G.[5]
			1 - Defining or constraining the value of aquifers and their potential functions					
1.1. 1.1a	Mean annual groundwater recharge depth	C	Long-term mean ground¬water recharge, including man-made components (return-flows, induced recharge, artificial recharge), divided by surface area of the whole aquifer. Indicator is expressed as mm/yr. This is calculated by dividing the volume of recharge by the surface area of the (country segment of the) aquifer. WaterGAP has calculated two versions of this indicator: 1.1: including artificial recharge and point recharge from surface water bodies 1.1a: including point recharge from surface water bodies	mm/year	1. Very high: > 300 mm/yr 2. High: 100-300 mm/yr 3. Medium: 20-100 mm/yr 4. Low: 2 -20 mm/yr 5. Very low: < 2 mm/yr	138 CS 7 TBA	258 CS 91 TBA	
1.2.	Annual amount of renewable groundwater resources per capita	C	Long-term mean ground¬water recharge, including man-made components, divided by the number of inhabitants of the area occupied by the aquifer WaterGAP uses 1.1 as input (see above)	m^3/yr/capita	1. Very High: > 10000 2. High: 5000 - 10000 3. Medium: 1000 - 5000 4. Low: 100 – 1000 5. Very low: < 100	138 CS 7 TBA	258 CS 91 TBA	258 CS 91 TBA
1.3.	Natural background groundwater quality	C	Percentage of the aquifer area where groundwater natural quality satisfies local drinking water standards.	%	1. Very high: > 80% 2. High: 60-80% 3. Medium: 40-60% 4. Low: 20 -40% 5. Very low: < 20%	119 CS 5 TBA		
1.4.	Aquifer buffering capacity	A	Ratio between volume stored and long-term mean groundwater recharge (=equivalent to mean residence time of groundwater)	year	1. Very High: > 1000 2. High: 500-1000 3. Medium: 100-500 4. Low: 10-100 5. Very Low: <10	125 CS 7 TBA		

1.5	Aquifer vulnerability to climate change	A	Extend of expected groundwater budget regime change in response to change in climate	-	1. Low: confined aquifers containing only fossil water or receiving negligible recent recharge. 2. Medium: weakly recharged aquifers with limited interaction with other components of the hydrological cycle, due to location at considerable depth and/or hydraulic confinement. 3. High: aquifers actively interacting with streams, atmosphere and/or sea (e.g. coastal aquifers, SIDS, shallow water-table aquifers, karst aquifers)	111 CS 7 TBA		
1.6	Aquifer vulnerability to pollution	A	Natural property of a groundwater system that depends on the sensitivity of the system to human impacts.		1. Low vulnerability 2. Moderate vulnerability to pollution 3. High vulnerability to pollution	46 CS 2 TBA		
2 - Role and importance of groundwater for humans and the environment								
2.1	Human dependency on groundwater	C	Percentage of groundwater in total water abstraction for all human water uses.	%	1. Very low: < 20% 2. Low: 20 -40% 3. Medium: 40-60% 4. High: 60-80% 5. Very high: > 80%	69 CS 2 TBA	258 CS 91 TBA	258 CS 91 TBA
2.2.	Human dependency on groundwater for domestic water supply	A	Percentage of groundwater in total water abstraction for domestic water use	%	1. Very low: < 20% 2. Low: 20 -40% 3. Medium: 40-60% 4. High: 60-80% 5. Very high: > 80%	61 CS 1 TBA	258 CS 91 TBA	
2.3.	Human dependency on groundwater for agricultural water supply	A	Percentage of groundwater in total water abstraction for agricultural water use WaterGAP only takes irrigation into account (excludes water used for watering cattle)	%	1. Very low: < 20% 2. Low: 20 -40% 3. Medium: 40-60% 4. High: 60-80% 5. Very high: > 80%	56 CS 1 TBA	258 CS 91 TBA	
2.4.	Human dependency on groundwater for industrial water supply	A	percentage of groundwater in total water abstraction for industrial water use	%	1. Very low: < 20% 2. Low: 20 -40% 3. Medium: 40-60% 4. High: 60-80% 5. Very high: > 80%	53 CS 1 TBA	258 CS 91 TBA	
2.5.	Ecosystem dependency on groundwater	A	Known extent of groundwater dependent ecosystems or percentage of the aquifer's area where the aquifer has a phreatic water level shallower than 5 m below surface	%	1. Very low: : < 5% 2. Low: : 5 – 10% 3. Medium: 10-25% 4. High: 25-50% 5. Very high: > 50%	75 CS 1 TBA		

2.6	Prevalence of springs	A	Total annual groundwater discharge by springs, divided by mean annual groundwater recharge	%	1. Very low: : < 5% 2. Low: : 5 – 10% 3. Medium: 10-25% 4. High: 25-50% 5. Very high: > 50%	79 CS 1 TBA		
3 - Changes in groundwater state								
3.1	Groundwater depletion	C	Observed current rate of long-term progressive decrease of groundwater storage (accompanied by steadily declining groundwater levels), expressed as an equivalent depth of water averaged over the aquifer.	mm/year	1. Absent to very low: < 2 mm/yr 2. Low: 2 -20 mm/yr 3. Medium: 20-50 mm/yr 4. High: 50-100 mm/yr 5. Very high: > 100 mm/yr	100 CS 10 TBA	258 CS 91 TBA	
3.2.	Groundwater pollution	C	Observed polluted zones as a percentage of total aquifer area (due to pollution caused water quality to exceed drinking water quality standards)	%	1. No pollution has been identified 2. Some pollution has been identified 3. Low: 0-30 % 4. Medium: 30 - 65% 5. High: 65 - 100 %	46 CS 2 TBA		
4 - Drivers of change and pressures								
4.1.	Population density	C	Number of people per unit of area on top of the aquifer	Persons/ km^2	1. Very low: < 1 p/km^2 2. Low: 1-10 p/km^2 3. Medium: 10-100 p/km^2 4. High: 100-1000 p/km^2 5. Very high: > 1000 p/km^2	502 CS 199 TBA	258 CS 91 TBA	258 CS 91 TBA
4.2	Groundwater development stress (including artificial recharge)	C	Total annual groundwater abstraction divided by long-term mean annual groundwater recharge WaterGAP has calculated two versions of this indicator: 4.2: including artificial recharge 4.2a: excluding artificial recharge	%	1. Very low: <2% 2. Low: 2-20% 3. Medium: 20-50% 4. High: 50-100% 5. Very high: > 100%	114 CS 7 TBA	258 CS 91 TBA	258 CS 91 TBA
5 – Enabling environment for transboundary aquifer resources management								
5.1	Transboundary legal framework	C	Existence, status and comprehensiveness of a binding agreement on the transboundary aquifer under consideration	Scores	1. Agreement with full scope for TBA management signed by all parties 2. Agreement with limited scope for TBA management signed by all parties 3. Agreement under preparation or available as an unsigned draft 4. No agreement exists, nor under preparation	192 CS 25 TBA		

5.2.	Transboundary institutional framework	C	Existence, mandate and capabilities of institutions or institutional arrangements for managing the transboundary aquifer under consideration (all types of interventions)	Scores	1. Dedicated transboundary institution fully operational 2. Dedicated transboundary institution in place, but not fully operational 3. National/Domestic institution fully operational 4. National/Domestic institution in place, but not fully operational 5. No institution exists for TBA management	191 CS 27 TBA		
6 – Implementation of groundwater resources management measures								
6.1	Control of groundwater abstraction	A	Current practices on the implementation of measures to control groundwater abstraction	Scores	1. Combination of Regulatory and Suasive measures applied 2. Regulatory/Direct measures applied (licensing) 3. Indirect/suasive measures applied (incentives/discentives) 4. No measures for control applied	167 CS 20 TBA		
6.2	Groundwater quality protection	A	Current practices on the implementation of groundwater quality protection	Scores	1. Combination of Regulatory and Suasive measures applied 2. Regulatory/Direct measures applied (licensing) 3. Indirect/suasive measures applied (incentives/discentives) 4. No measures for control applied	159 CS 17 TBA		

[1]: C: Core indicator; A: Additional indicator
[2]: Available indicators for the current state
[3]: Available indicators for projections for 2030 and 2030
[4]: G.I: Global Inventory (= questionnaire survey)
[5]: W.G: WaterGAP model
CS: Indicators available at level of Country Segment
TBA: Indicators available at level of Transboudary Aquifer. For WaterGAP this includes merged aquifers.

The TWAP Groundwater IMS can be accessed via: *http://twapviewer.un-igrac.org*

Figure 2.5. TWAP Groundwater Information Management System – Landing page.

About TWAP

Recognizing the value of transboundary water systems and the fact that many of them continue to be degraded and managed in fragmented ways, the Global Environment Facility Transboundary Water Assessment Programme (GEF TWAP) was developed. The Programme aims to provide a baseline assessment that identifies and evaluates changes in these water systems caused by human activities and natural processes, and the consequences such have on dependant human populations. The project is the first truly global comparative assessment for transboundary aquifers, lakes, rivers and large marine ecosystems, as well as a thematic evaluation of the open ocean, through institutional partnerships that hope to seed future global assessments. The project results are envisioned to assist the GEF and other international organizations in setting priorities for supporting the conservation of transboundary water systems. More information on TWAP including final reports can be found on www.geftwap.org

About this portal

This portal gives access to the map based results from the Groundwater component of the Transboundary Waters Assessment Programme. The data shown in this portal have been made available by national experts from countries involved in the TWAP Groundwater project. It also includes the results from scenario analyses using the global WaterGAP model (University of Frankfurt, Germany) and a study on groundwater systems of small island developing states, also called SIDS (Simon Frasier University, Canada). More information on TWAP Groundwater, including reports on methodology and outcomes, can be found on www.twap.isarm.org

Functionalities of the IMS

The TWAP Groundwater IMS is web-based and publically accessible, which means that anyone with an internet connection and web browser can use it: there is no need to register as a user (Figure 2.6). The core of the system is the map of the 199 TWAP TBAs. Data from the TWAP Groundwater assessment can be visualised on this map or can be downloaded as excel tables for further processing. In a similar way, the data describing the Groundwater Systems of the Small Island Developing States can be visualised and downloaded. Data can be viewed per country segment or for the whole TBA, and overlays of different map layers can be made. For both the TBAs and the SIDS, the system contains all indicators from the Global Inventory (questionnaire survey) and the Basic Parameters and variables, which are all the data collected via the questionnaires. For the larger TBAS (large than 20 000 km^2), indicators calculated from the WaterGAP model are also available: current state situation and future scenarios for 2030 and 2050.

The system also gives access to all 197 Transboundary Aquifer Information Sheets and the Information Sheets on the Groundwater Systems of the Small Island Developing States, which can all be downloaded in pdf-format.

TWAP Groundwater is part of the larger TWAP programme covering five water systems. So that users can explore all the main results from all TWAP components, a Central TWAP Data Viewer has been developed which links assessment results from Components and additional data and indicators and presents these in a harmonized way. This viewer/data portal is accessible via www.geftwap.org. Data from the TWAP Groundwater IMS are made available to the Central TWAP Data Viewer via Web Map[18] Service (WMS) so that both viewers always contain the same versions

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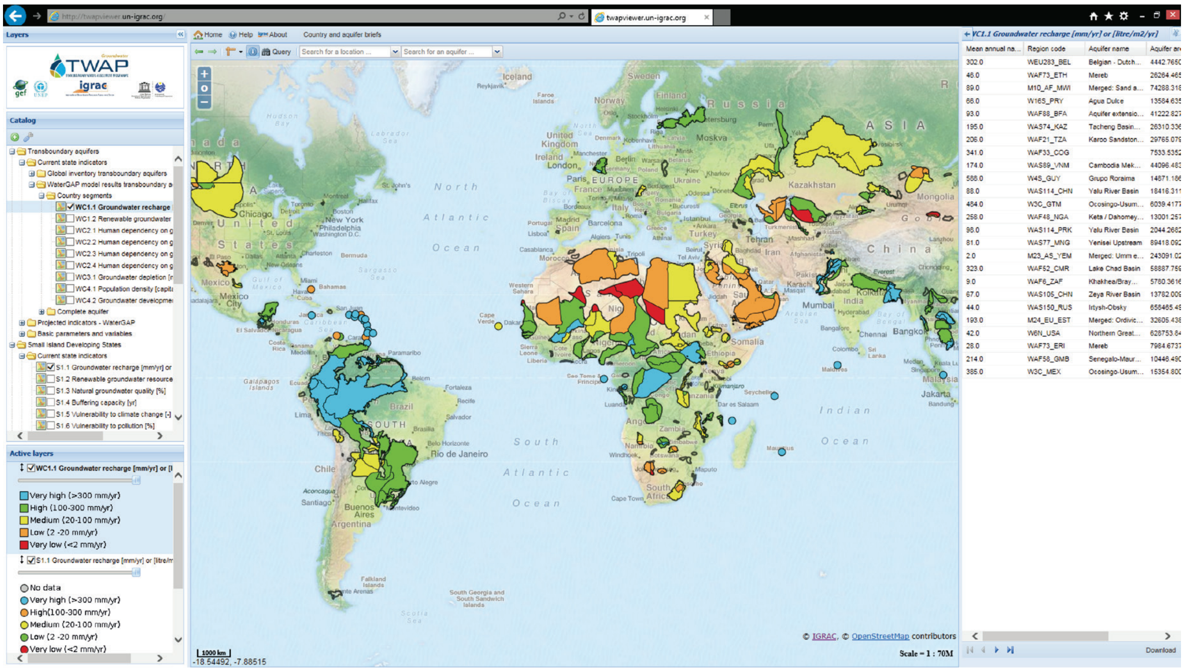
[18] WMS is a worldwide standard developed by the Open Geospatial Consortium: www.opengeospatial.org.

of data, since the data remain on one server. The same WMS protocol can be used to combine maps from external sources with data in the TWAP Groundwater IMS, for example data from WHYMAP[19] .

The TWAP Groundwater IMS has been designed in such a way that use of the IMS is intuitive, and the basic functionality should not need explanation. An on-line user manual will be made available for the more advanced operations.

Figure 2.6. Example from TWAP Groundwater Information System.



VC1.1 Groundwater recharge [mm/yr] or [litre/m2/yr]

Mean annual na...	Region code	Aquifer name	Aquifer ar
302.0	WEU283_BEL	Belgian - Dutch...	4442.765
46.0	WAF73_ETH	Mereb	26264.46
89.0	M10_AF_MWI	Merged: Sand a...	74288.31
66.0	W16S_PRY	Agua Dulce	13584.63
93.0	WAF88_BFA	Aquifer extensio...	41222.82
195.0	WAS74_KAZ	Tacheng Basin...	26310.33
206.0	WAF21_TZA	Karoo Sandston...	29765.07
341.0	WAF33_COG		7533.535
174.0	WAS89_VNM	Cambodia Mek...	44096.48
588.0	W4S_GUY	Grupo Roraima	14871.18
88.0	WAS114_CHN	Yalu River Basin	18416.31
484.0	W3C_GTM	Ocosingo-Usum...	6039.417
258.0	WAF48_NGA	Keta / Dahomey...	13001.25
98.0	WAS114_PRK	Yalu River Basin	2044.268
81.0	WAS77_MNG	Yenisei Upstream	89418.09
2.0	M23_AS_YEM	Merged: Umm e...	243091.0
323.0	WAF52_CMR	Lake Chad Basin	58887.75
9.0	WAF6_ZAF	Khakhea/Bray...	5780.361
67.0	WAS105_CHN	Zeya River Basin	13782.00
44.0	WAS150_RUS	Irtysh-Obsky	658465.4
193.0	M24_EU_EST	Merged: Ordivic...	32605.43
42.0	W6N_USA	Northern Great...	628753.8
28.0	WAF73_ERI	Mereb	7984.673
214.0	WAF58_GMB	Senegalo-Maur...	10446.49
385.0	W3C_MEX	Ocosingo-Usum...	15354.80

2.3. Information intensity and reliability

2.3.1. Delineation of aquifer boundaries

Worldwide studies of TBAS started around 2000 with the launch of the International Shared Aquifer Resources Management programme (ISARM) by UNESCO-IHP. The first maps providing a global overview of TBAs was the WHYMAP map Groundwater Resources of the World : Transboundary Aquifer Systems (Struckmeier et al., 2006). This map showed the approximate location of about 100 TBAs (Figure 2.7). Since then there has been progressive development in the knowledge of TBAs of the world and dissemination of this knowledge. More and more TBAs have been defined and information has been shared with the international community through regular map updates.
The starting point for TWAP Groundwater was the map Transboundary Aquifers of the World – Update 2012 (IGRAC, 2012). It already showed more than 400 TBAs an increase of 300 TBAs in merely 6 years.

Initially the 166 aquifers larger than 5 000 km^2 were selected for TWAP, but the final number of TWAP TBAs changed to 199. The number changed because national experts suggested adding some aquifers smaller than 5 000 km^2 which, despite being small, are often considered of large local importance. There was also a significant number of TBAs which had only recently been mapped and studied or which were simply not know to the international community prior to TWAP. Also some of the transboundary aquifers from the 2012 map where not considered in the final list of TWAP TBAs, either because national/regional experts no longer considered the aquifer to be a TBA

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[19] WHYMAP: Worldwide Hydrogeological Mapping and Assessment Programme www.whymap.org.

because of its limited horizontal hydraulic continuity, or because existing smaller aquifers were merged into newly-defined larger aquifers on the basis of more recent insights into regional geology.

Contributions of national and regional experts via the questionnaire survey and the regional workshops resulted in a large number of aquifers with improved or completely new delineations of boundaries. Out of 199 TWAP TBAs, only 53 were not modified from the 2012 map. There were minor modifications of the boundary (change of surface area less than 10 per cent) for 28 aquifers, significant changes to the delineation were made (change of surface area of aquifer > 10 per cent) for 65 aquifers, and 53 aquifers are new since the 2012 map.

Table 2.4 provides an overview of TWAP improvements of aquifer delineations,including accuracy and degree of harmonization

Table 2.4. Overview of TWAP improvements of aquifer delineations, including accuracy and degree of harmonization.

Changes since 2012 map*	No. of TBAs	Status of delineation	Confirmed	Partially confirmed	Unconfirmed	Harmonized	Not harmonized and/or not delineated
2012 TBA No changes	53	Confirmed	38			36	2
		Partially confirmed		6		1	5
		Unconfirmed			9	-	9
2012 TBA Minor changes	28	Confirmed	26			23	3
		Partially confirmed		2		-	2
		Unconfirmed			-		
2012 TBA Significant changes	65	Confirmed	46			32	14
		Partially confirmed		18		1	17
		Unconfirmed			1	1	-
New TBA	53	Confirmed	35			32	3
		Partially confirmed		17		-	17
		Unconfirmed			1	-	1
Total	199		145	43	11		
						126	73

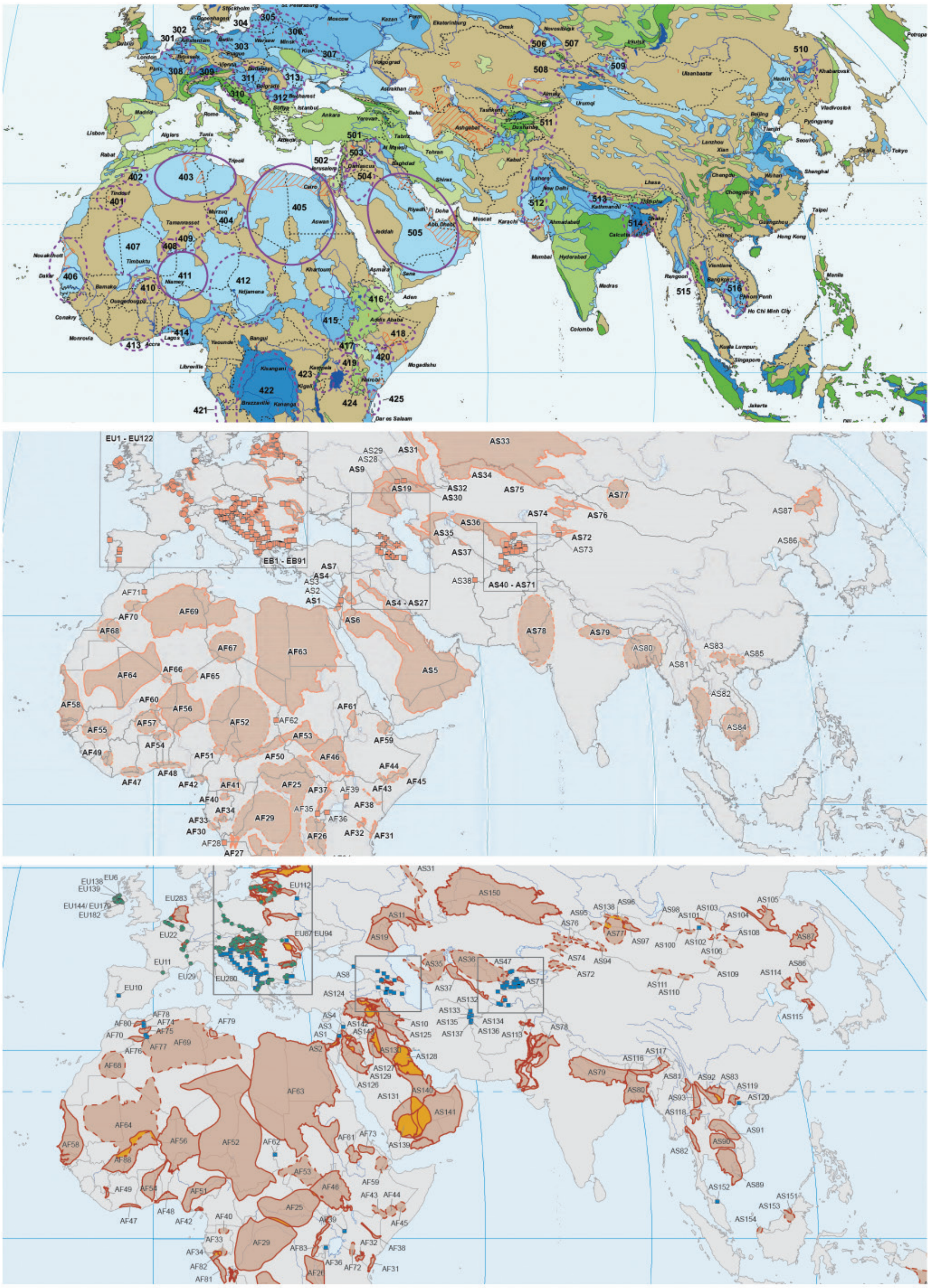
Explanation: Confirmed: all countries sharing have confirmed the delineation of their country segment. This delineation is based on varying criteria and available data, such as sometimes the outcrop of geological formations or topographical features. Partially unconfirmed: at least one country has not confirmed the delineation. Unconfirmed: TBA is not yet delineated. Harmonized: Delineation is harmonized between states. Not harmonized and/or not delineated: Boundary Delineation is not harmonized between all states or the location of the aquifer is only known by approximation (boundary is not delineated at all).

Reliability of aquifer maps

Mapping TBAs (or aquifers in general) is not straightforward. Accurate mapping requires costly and in-depth studies into the three-dimensional geological deposits and structures to define the hydrogeological units within these structures/deposits. This requires geological mapping, borehole information on geology, borehole yield and water quality, pumping tests to establish aquifer characteristics, geophysical studies, etc. Even when all these data are available it is still not always trivial how to define the three-dimensional boundaries of a TBA or aquifer system. Different countries might use different criteria to define hydrogeological units, or their base maps might not have been harmonized. In many cases, the delineation is based on the mapping of the outcrop of the aquifer. For regions where data on hydrogeology are not available, the boundaries of aquifers may even have to be inferred from topographical features such as surface water divides. Boundaries might also change over time as more detailed

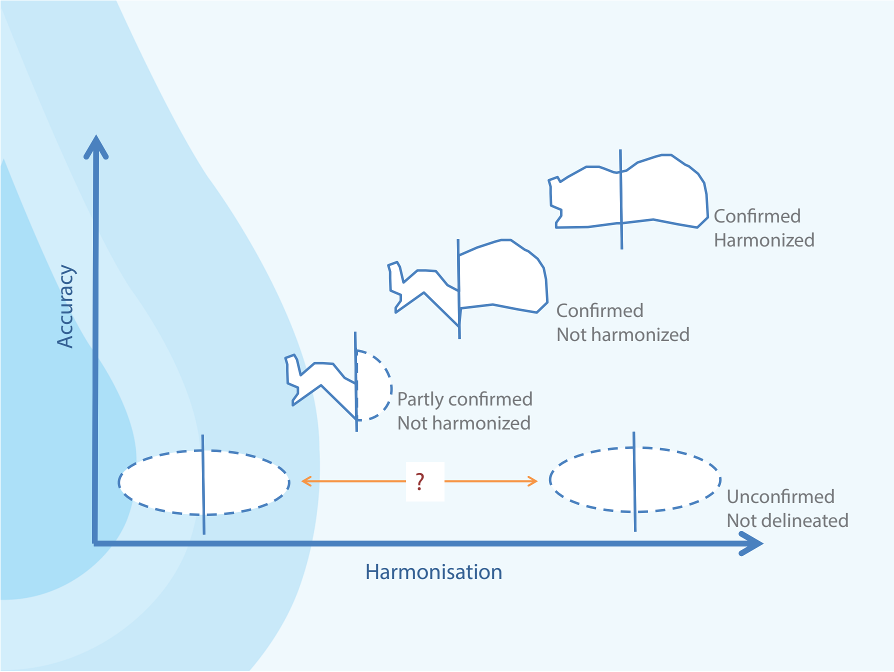
Figure 2.7. Progressive development in the global knowledge of TBAs from 2006-2015.

Top: Detail from WHYMAP and the World Maps of Transboundary Aquifer Systems (Struckmeier et al, 2006)
Middle: Detail from map Transboundary Aquifers of the World - update 2012 (IGRAC, 2012)
Bottom: Detail from map Transboundary Aquifers of the World – update 2015 (IGRAC, 2015) based on TWAP data



knowledge becomes available. For example, an aquifer originally reported as a single-layer transboundary aquifer, might later be defined as a transboundary aquifer system when individual aquifers/ aquifer layers have been mapped. In the framework of TWAP it is not possible to harmonize the methodology for the delineation of aquifers worldwide, but national experts were encouraged in regional workshops to harmonize the delineation of the aquifer boundary as far as possible between the countries sharing the aquifer. This resulted in a large number of improved even completely new delineations of TBAs. Figure 2.8 shows a graphical representation of the development in the accuracy of the delineation and harmonization between countries sharing the aquifer and Table 2.4 lists the degree of accuracy and harmonization. Table 2.4 shows that, for the majority of aquifers, the delineations have been now confirmed and are harmonized between countries (123 TBAs are confirmed and harmonized)[20]. Only ten TWAP TBAs are marked on the map as circles indicating the approximate location. 41 TBAs have been delineated in at least one country segment but information is still missing from one of the countries sharing (in most cases those unable to contribute to TWAP). Compared to the 2012 map of Transboundary Aquifers of the World (IGRAC, 2012) this is a significant improvement. The status of the delineation for each TBA is presented in the online appendices (see twap.isarm.org).

Figure 2.8. Graphical representation of accuracy and harmonization in delineation of TBA boundaries.



Through the questionnaires, the national experts were also asked to describe the type of information on which the aquifer delineation is based, including literature references. This can be no-flow boundaries, lithological/geological properties, groundwater quality, topography or administrative boundaries. For 39 per cent of the country segments this information has been provided (total return of questionnaires is 54 per cent), and the majority of those aquifer delineations is reported to be based on a combination of criteria.

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[20] When the boundaries are defined on the basis of the outcrop of geological formations, the „confirmed" aquifer boundaries may consist in different polygons despite corresponding to a single TBA.

2.3.2. Global Inventory of TBAs (questionnaire survey)

Information intensity

In the preparation phase of TWAP Groundwater it was decided to take national segments of the TBA system as the primary spatial unit for TWAP groundwater activities (UNESCO-IHP et al. 2012). The 199 TWAP Transboundary Aquifers consist of 506 country segments. National and regional experts provided data for about 54 per cent of the country segments (Table 2.5). These are divided over 160 of the TBAs (80 per cent of all TWAP TBAs). This means that although there are no data for 46 per cent of the country segments, there are only 20 per cent of the TBAs for which there are no data at all from the Global Inventory, see Figure 2.9. The availability of data from the Global Inventory for each TBA and country segment is listed on a dedicated online appendix (see twap.isarm.org).

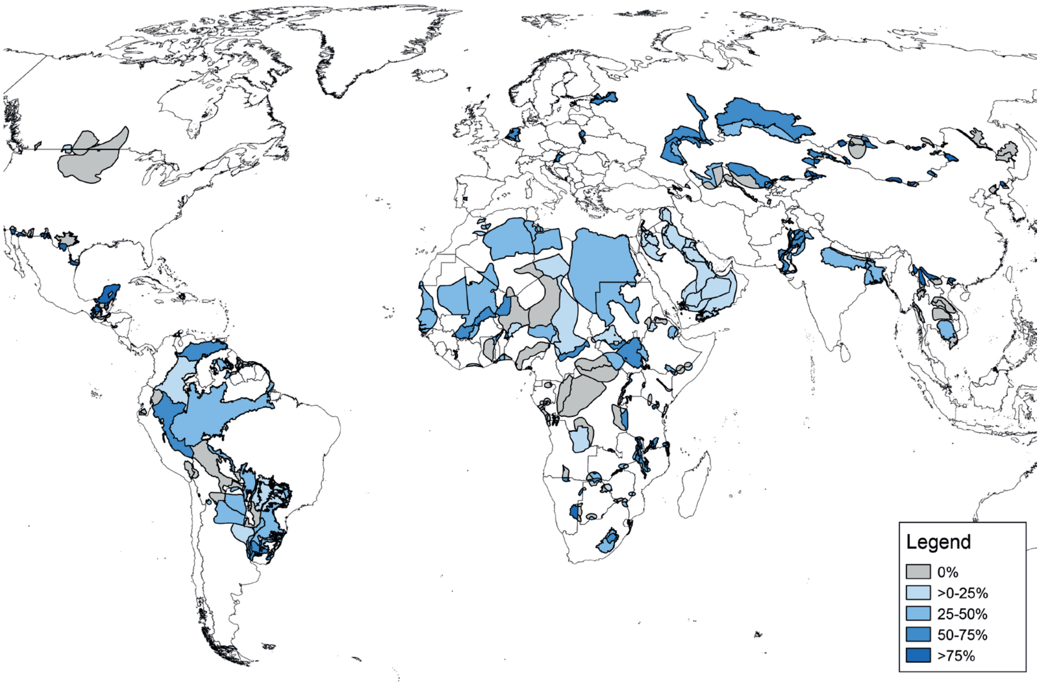
Table 2.5. Overview of data yield from Global Inventory per continent

	Aquifers	Country Segments	
		Total	Percentage of country segments for which data were provided through questionnaires
Africa	64	188	57%
Asia	68	154	52%
Europe	10	27	74%
North America	32	66	41%
South America	25	68	51%
Worldwide	199	503	54%

There are 21 TBAs for which data were provided at the level of the whole aquifer rather than the country level, because recent studies were available with data at the TBA level and the data did not enable the provision of information at country level. These are all aquifers in Northern Africa and Western Asia. The online appendix “Global Inventory Data Overview per Transboundary Aquifer and per Country Segment” (see twap.isarm.org) shows, for each aquifer, whether data have been provided at the country segment or the aquifer level.

The TWAP Groundwater questionnaires are divided into 11 sections. Sections 5 – 9 are the most important concerning aquifer geometry, hydrogeological aspects, environmental aspects, socio-economic aspects, and legal and institutional aspects. Table 2.6 and Figure 2.10 show the data yield per section of the questionnaire and categorized per continent. The data show similar patterns across all continents: best response is on aquifer geometry, followed by hydrogeological information and the legal and institutional questions. Lowest availability of data is on environmental aspects and groundwater quality, and data on socio-economic aspects (e.g. groundwater usage and dependence) are particularly sparse.

Figure 2.9. Map showing data yield on Global Inventory. See also Table 2.5.

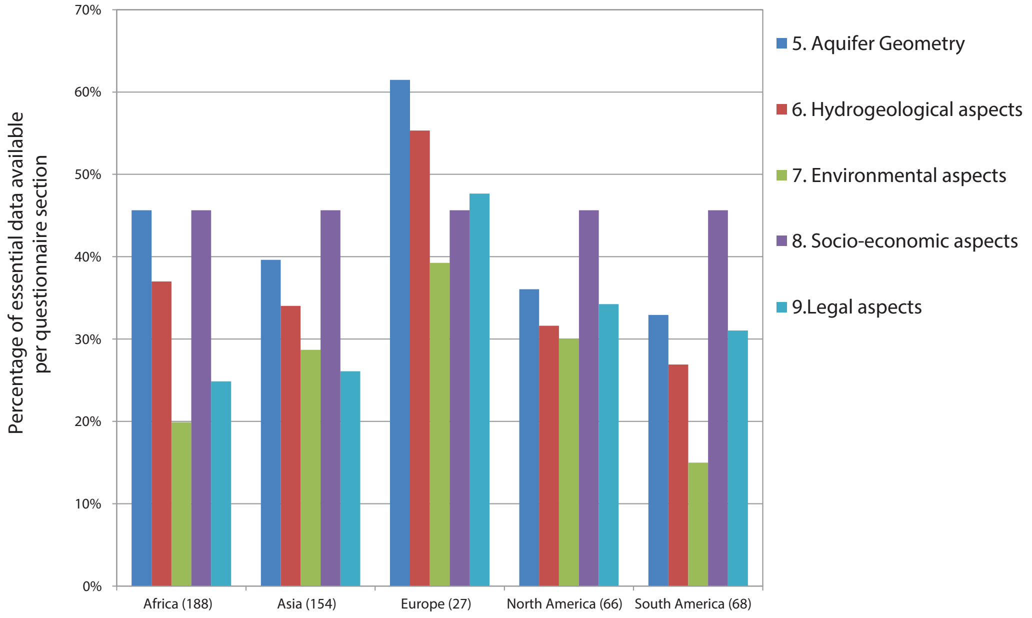


The Global inventory unlocked a huge amount of data from national and local level and grey literature. But it is clear that governmental institutions in many countries are weak in data management and ownership. National experts indicated that more data may be available from the private sector, but this information is difficult to unlock. From regional workshops it became evident that the majority of countries and national experts are very willing to share data. Nevertheless, from some discussions in the regional workshops, it also seems that there may be a few hidden issues with national experts shying away from the responsibility for sharing bad news, for example on pollution or groundwater depletion, or to share data, such as water use, which are considered sensitive by some countries.

Table 2.6. Average data yield per section of the questionnaire and categorized per continent

Questionnaire section	Africa	Asia	Europe	North America	South America	World-wide
5. Aquifer Geometry	46%	40%	61%	36%	33%	42%
6. Hydrogeological	37%	34%	55%	32%	27%	35%
7. Environmental	20%	29%	39%	30%	15%	24%
8. Socio-economic	12%	24%	27%	31%	5%	18%
9. Legal aspects and Institutional	25%	26%	48%	34%	31%	29%
Total questionnaire	**28%**	**31%**	**46%**	**32%**	**22%**	**30%**
Total number of country segments in region	188	154	27	66	68	503

Figure 2.10. Average data yield per section of the questionnaire and per continent. The number in brackets behind continent represents the total number of TBA country segments in the continent.



TWAP groundwater indicators

The TWAP groundwater indicators are calculated by combining answers from the questionnaires. This means that if only some of the relevant data have been provided, it is not possible to calculate the indicator. The only exception is indicator 4.1 population density: this is calculated on the basis of the aquifer map and grid information on population from CIESIN (2005). This means that this indicator is available for all country segments.

Table 2.7 and Figure 2.11 give an overview of the available indicators per region as a percentage of all country segments in the region. The amount of country segments for which indicators could be calculated based on the Global Inventory is limited (Figure 2.12). The table clearly shows that in particular the indicators describing human dependence on groundwater (2.1) and long term depletion (3.1) could only be calculated for a small proportion of country segments (15 per cent and 24 per cent worldwide respectively).

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Table 2.7. Availibility of core indicators

	Africa	Asia	Europe	North America	South America	Worldwide
Total number of country segments in region (=100%):	188	154	27	66	68	503
Indicator						
1.1 Recharge	34%	47%	56%	32%	10%	36%
1.2.Renewable groundwater resources per capita	34%	47%	56%	32%	10%	36%
1.3 Natural background quality	20%	44%	44%	30%	21%	30%
2.1 Human dependence on groundwater	13%	14%	30%	30%	0%	15%
3.1 Long term groundwater depletion	16%	36%	56%	27%	6%	24%
3.2 Groundwater pollution	11%	6%	19%	21%	0%	10%
4.1 Population density	100%	100%	100%	100%	100%	100%
4.2 Groundwater Development Stress	25%	44%	44%	30%	9%	30%
5.1 Transboundary Legal Framework	44%	50%	59%	38%	50%	47%
5.2 Transboundary Institutional Framework	44%	49%	67%	36%	51%	47%

Percentage of the total number of country segments and categorised per continent.

Figure 2.11. Availibility of core indicators Percentage of the total number of country segments and categorized per continent. Number in brackets behind continent: total number of TBA country segments in the continent.

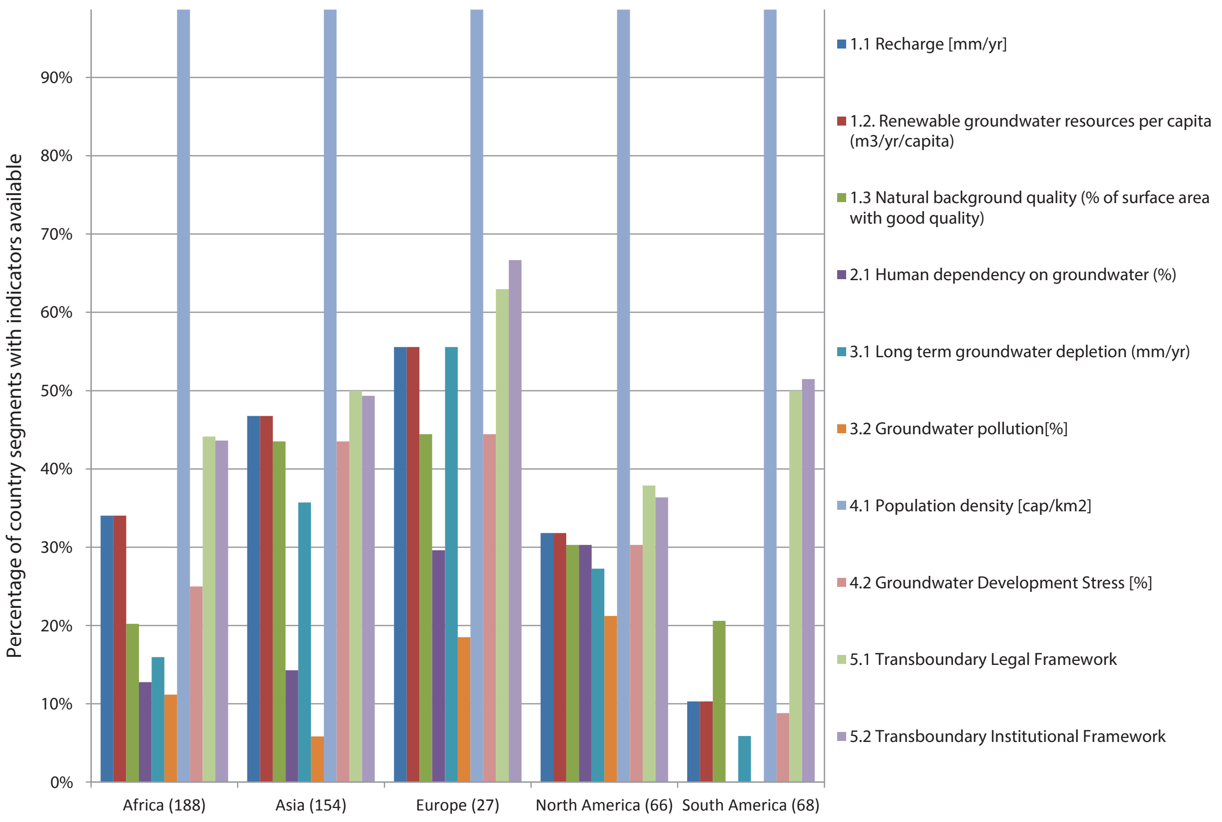
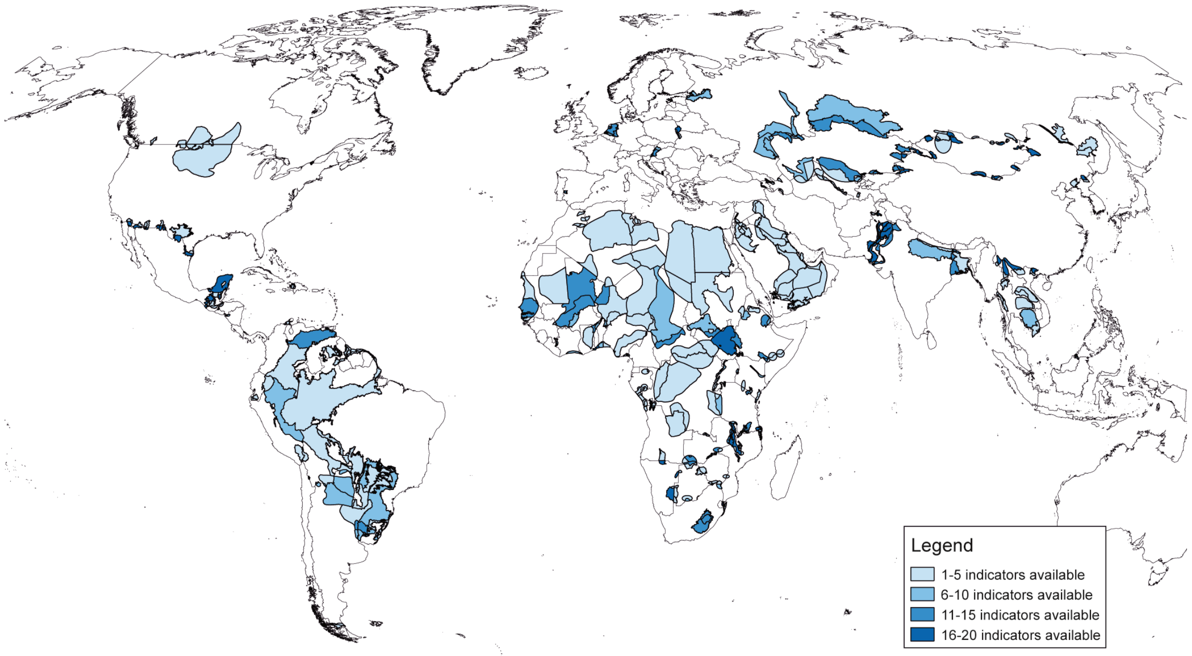


Figure 2.12. Map indicating available indicators (core indicators and additional indicators) per country segment.



Box 3. Global Inventory: Conclusions on data intensity

After TWAP, considerable gaps in publicly available information on TBAs still remain. Local knowledge harnessed through the regional expert networks is highly valuable and for some aspects critical, but is far from providing a globally complete and sound picture.

The TWAP Global Inventory contains data for about 54 per cent of the 502 country segments that constitute the total of 160 TBAs inventoried. This means that information for the majority of these aquifers is only available for some of the countries sharing the aquifer. Data can therefore only be aggregated to the level of the complete aquifer for a very small number of aquifers.

Based on the Global Inventory, some but not all indicators are available for about 30 per cent of the country segments. The indicators on groundwater pollution and human dependence on groundwater are only available for 10 to 15 per cent of the country segments. Data on socio-economic, quality and environmental aspects are particularly sparse.

Reliability of data

TWAP Groundwater was executed following the ISARM approach philosophy. This means that national experts provide data, so that local knowledge can be incorporated. Being involved in a project like TWAP also gives national experts the opportunity to liaise with experts from neighbouring countries. This is crucial for future transboundary research and governance of the transboundary groundwater resources. Direct involvement of national experts also creates a stronger sense of ownership.

A complicating factors in this approach is the consistency and accuracy of the data. Given the nature of the Global Inventory, where data have been collected by means of questionnaires with more than 200 national experts from 76 countries involved, it is not possible to quantify reliability of the data exactly. There are many factors influencing accuracy and reliability, and many are related to the surface area of the aquifer, and hence the accuracy of the aquifer delineation and the proper understanding of the three-dimensional structure of the aquifers (conceptual model), for which in many cases only limited and not sufficiently detailed information is available. Reliability and accuracy of the data will also vary considerably between countries, depending on the amount of groundwater-related research and monitoring which has been done and whether or not dedicated studies have been done on the transboundary aquifer in question.

Because of the limited data availability, national experts were also asked to provide data aggregated at the level of the country segments. This means that they had to provide one value representing the whole country segment of the aquifer. Aggregating data to this level is particularly difficult when there is poor geographical coverage of data, especially for some of the extremely large country segments. For the purpose of TWAP Groundwater it was not possible to define and apply harmonized methods for aggregation of data to the country segments. First, the logistics of this operation are too large for a relatively short and worldwide programme: applying harmonized aggregation methods would require some kind of training or instruction of national experts applying these methods, and funds for interaction with national experts were very limited. Second, the type of data available in different countries varies: in some countries, geo-database including long-term monitoring data may be available which can be used for accurate aggregation techniques. In others, data may only be available from a single project in a specific part of the aquifer. There will also be situations in which the original data are no longer available or accessible, and where the national experts will have had to rely on interpreted results from previous studies (either peer-reviewed literature or grey literature). Estimating representative aggregated values for the latter situations is not a straightforward mathematical exercise but requires expert judgement. Values derived from such situations will in many cases be less reliable. To get an indication on the accuracy and reliability of the data, national experts were asked to provide metadata with their information: each main question was followed by question(s) relating to the source of information, data density, etc. National experts were also asked to provide references to the literature that they used to fill out the questionnaire. The metadata are preserved in the database and can be downloaded from the TWAP Groundwater IMS together with all other data.

Once national experts had finalized their responses to the questionnaires, regional coordinators performed basic quality checks on the data provided. UNESCO-IHP consultants involved in editing the transboundary aquifer information sheets, as well as IGRAC, also performed some basic checks of values, by checking if the answers provided were within a likely range. National experts were contacted on these issues, and this often resulted in improved or corrected information. With large numbers of national experts providing data essentially on a voluntary basis, results cannot be expected to be without errors and some mistakes.

Some indications of indicator reliability can be obtained by comparing the indicator values from the Global Inventory to the indicators calculated using the WaterGAP model (see next section). It is however not possible to say which information source is more reliable, since a global model like WaterGAP obviously also has its limitations. The current TWAP Groundwater database is a good reflection of the current state of knowledge on transboundary groundwater worldwide, but accuracy of the data in the database cannot be guaranteed. Clearly more research and consistent monitoring is needed to fill data gaps and improve the accuracy of existing data.

2.3.3. WaterGAP modelling of Transboundary Aquifers

WaterGAP data availability

Goethe University Frankfurt (UF) contributed to the TWAP project by simulating groundwater resources and groundwater use for selected TBAs and country segments of TBAs using an improved version of the global water resources and use model WaterGAP 2.2 (Riedel and Döll 2015). The work focused on quantifying six core indicators and three additional indicators for current conditions. WaterGAP was also used to calculate climate and water-use scenarios for 2030 and 2050 (‘projected groundwater stress indicators’). For these scenarios, four of the core indicators have been quantified.

With the WaterGAP model it is not possible to calculate any indicators related to groundwater quality or indicators requiring three-dimensional conceptualization of the aquifer (such as aquifer buffering capacity, or aquifer vulnerability to climate change or to pollution). It obvious that indicators related to the legal and institutional setting of TBAs also cannot be calculated using WaterGAP data. Tables 2.3 provides an overview of indicator availability from WaterGAP, per country segment and per TBA, and of indicators calculated based on WaterGAP for current conditions and the future scenarios.

The WaterGAP model covers all continental land area, except Antarctica, on a 0.5° grid (55 km × 55 km at the equator). This means that in theory the WaterGAP model could be used to calculate indicators for all TWAP TBAs. But as input data are limited, UF decided to use WaterGAP model results to calculate only indicators for transboundary aquifers larger than 20 000 km^2.

Using the sinusoidal projection, 105 TBAs larger than 20 000 km^2 were identified in the TWAP TBA shapefile (status December 2014). Some of these aquifers are (partly) overlapping on the map, representing aquifers at different depths. WaterGAP, like other global-scale hydrological models, cannot compute the water balance of individual overlying aquifers. The model concept is such that there is one (unconfined) aquifer that receives all groundwater recharge from the soil and surface water bodies above it and that all groundwater abstractions are taken from this one aquifer. Therefore, it was necessary to merge overlying aquifers. 22 TBAs were merged into 8 TBAs resulting in a total of 91 TBAs for the WaterGAP assessment. Information on the merged TBAs is presented in Table 2.8. An example of merged aquifers is shown in Figure 2.13. Appendix 1 lists all merged aquifers.

All indicators were computed at different scale levels: at the 0.5° grid-cell level, for each transboundary aquifer, and for each country segment of the transboundary aquifers. The 91 transboundary aquifers consist of 258 country segments. For TBA- and country segment-based indicators, the grid cell-based populations and volumes of water use and groundwater recharge in km^3 were first aggregated over the TBAs and country segments and then divided by

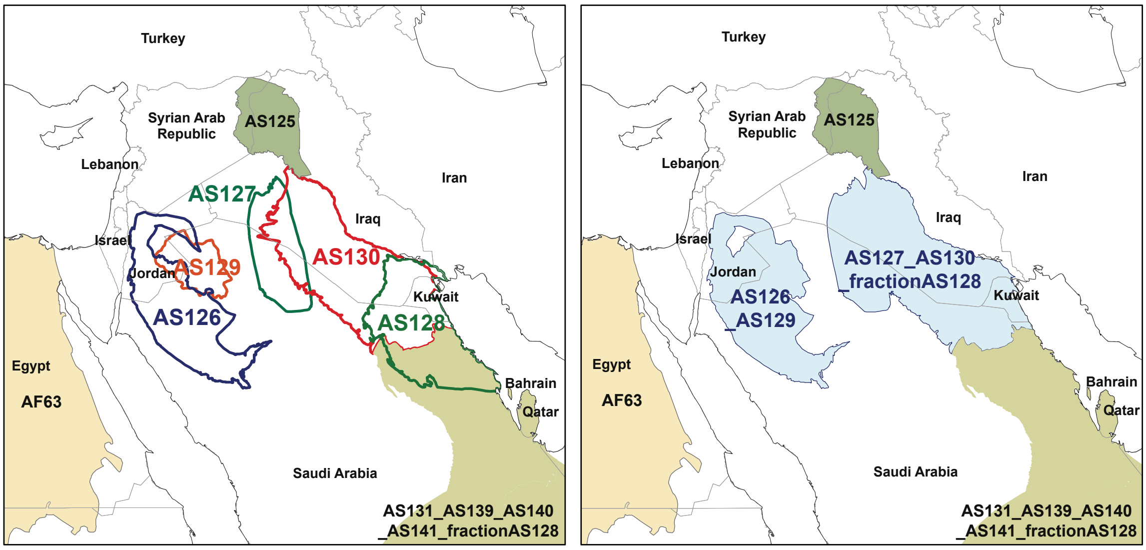
Table 2.8. TBAs merged for the WaterGAP assessment.

ID of merged TBA	Aquifers included	Associated countries
AS126_AS129	AS126: Saq-Ram Aquifer System (West) AS129: Tawil Quaternary Aquifer System: Wadi Sirhan Basin	Jordan, Saudi Arabia
AS127_AS130 _fractionAS128 (referred to as AS127_ in this report)	AS127: Wasia-Biyadh-Aruma Aquifer System (North): Sakaka-Rutba; AS128 Neogene Aquifer System (South-East): Dibdibba-Kuwait Group (Fraction of aquifer only) AS130: Umm er Radhuma-Dammam Aquifer System (North): Widyan-Salman;	Iraq, Kuwait, Saudi Arabia
7S_8S	7S: Coesewijne; 8S: A-Sand/B-Sand	Guyana, Suriname
EU108_EU109	EU108: Ordivician - Cambrian groundwater body; EU109: Cambrian - Vendian - Voronka groundwater body / Lomonosovsky aquifer	Estonia, Russia
AF19_AF24	AF19: Sand and Gravel Aquifer; AF24: Weathered basement	Malawi, Tanzania, Zambia
4N_19N	4N: Poplar; 19N: Judith River	Canada, United States of America
20S_21S_22S_25S_26S	20S: Caiua-Bauru-Acaray Aquifer; 21S: Sistema Acuífero Guaraní; 22S: Serra Geral; 23S: Litoral-Cretácico; 26S: Salto-Salto Chico	Argentina, Brazil, Paraguay, Uruguay
AS131_AS139_AS140 _AS141_fractionAS128 (referred to as AS131_ in this report)	AS128 Neogene Aquifer System (South-East): Dibdibba-Kuwait Group (Fraction of aquifer only) AS131: Wajid Aquifer System; AS139: Wasia-Biyadh-Aruma Aquifer System (South): Tawila-Mahra/ Cretaceous Sands; AS140: Umm er Radhuma-Dammam Aquifer System (South): Rub' al Khali, (Centre): Gulf	Oman, Saudi Arabia, United Arab Emirates, Yemen, Bahrain, Qatar

See also Figure 2.4

the respective unit of area. For grid cells intersected by TBA boundaries, the respective fraction of grid-based model output was taken into account. In grid cells where TBA boundaries overlap slightly, the grid cell values were assigned to both TBAs, leading to a negligible double-counting of grid-based data.

Figure 2.13. Example of TBA overlaps (left) and resulting aquifers (right).



See Appendix 1 for all merged aquifers.

Box 4 . Overview of data available from WaterGAP

Results from WaterGAP are available for 105 TBAs larger than 20 000 km^2, but 22 overlapping aquifers were merged into 8 larger units resulting in a total of 91 WaterGAP TBAs. Results are available at the level of country segments and TBA level.

Based on WaterGAP results, six core current status indicators and three additional indicators were calculated. Scenario analyses for 2030 and 2050 are available for four of these core indicators.

WaterGAP data reliability or accuracy

Since global hydrological models rely on uncertain data and simplifying model assumptions, the accuracy of model output is necessarily limited. To obtain meaningful results despite these limitations, WaterGAP is calibrated against observed mean annual river discharge at 1 319 gauging stations, covering around 50 per cent of global land area (Müller Schmied et al. 2014), such that estimated renewable water resources in river basins are reasonably well represented by WaterGAP. Groundwater recharge estimates have been validated by regional experts as they were included in UNESCO's Groundwater Resources of the World map (WHYMAP). However, given the large amount of input data for complex global models like WaterGAP, and a limited amount of reliable data to calibrate and/or verify the model, it is extremely hard to quantify the reliability and accuracy of the WaterGAP model results.

Comparison of groundwater recharge with estimates from national experts

Some indications on reliability of the data can be obtained by comparing model results with data obtained from other sources through the Global Inventory. WaterGAP model results of groundwater recharge (diffuse and from surface water bodies) in different African TBAs were evaluated by national experts within the framework of the

TWAP Groundwater Regional Workshop for East and Southern Africa. In general, only modelled diffuse groundwater recharge was assessed; information on groundwater recharge from surface water bodies was not available. In total, results for five TBAs could be compared with independent estimates:

- According to national experts, groundwater recharge over the Karoo Sedimentary aquifer (AF1) as modelled by WaterGAP is too high in South Africa (30 mm/yr) and too low in Lesotho (17 mm/yr). Given the small range of these values, model results are considered to be in good accord with independent estimates.
- In Tanzania (AF21: Karoo Sandstone aquifer), WaterGAP possibly overestimates diffuse groundwater recharge of 206 mm/yr aggregated over the TBA by a factor of 1.7. However, a reduction of groundwater recharge to the estimated 120 mm/yr would still result in a low classification of groundwater development stress.
- For the Aquifere du Rift (AF83) in Uganda, WaterGAP results are within the range of groundwater recharge between 25 and 125 mm/yr given by national experts.
- In Djibouti (AF59: Afar Rift valley/Afar Triangle aquifer), modelled diffuse groundwater recharge of 2 mm/yr was considered too low by national experts. An evaluation of groundwater recharge under surface water bodies, which is model at 120 mm/yr averaged over the TBA, was not possible. For the Ethiopian part of the aquifer, national experts confirmed modelled diffuse groundwater recharge of 8 mm/yr, while return flows of approximately 3 mm/yr were considered too high. Groundwater recharge under surface water bodies accounts for 70 mm/yr aggregated over the TBA.
- Modelled diffuse groundwater recharge in the Gedaref aquifer (AF61) in Ethiopia was confirmed. Modelled recharge from surface water bodies in this area is zero.

In conclusion, indicator results are highly uncertain in regions where the contribution of surface water bodies to total groundwater recharge is large, as modelled for example in Ethiopia, Eritrea and Djibouti. Without dedicated studies it is not obvious which data source (Global Inventory or WaterGAP model results) is most accurate, but combining the results is assumed to provide a likely range.

Comparison of groundwater recharge with Margat and van der Gun (2013)

Estimates of total groundwater recharge and the contribution of surface water bodies (mainly floods) are provided in Margat and van der Gun (2013) for different regions in the world. In Table 2.9, natural diffuse groundwater recharge ($R_{g,nat}$)and point groundwater recharge under surface water bodies ($Rg,_{swb}$) as modelled by WaterGAP are compared with these estimates. Groundwater recharge estimates of Margat and van der Gun (2013) are likely to neglect groundwater recharge from irrigation return flows. Modelled and estimated contributions from surface water bodies cannot be meaningfully compared, since Margat and van der Gun mainly consider groundwater recharge from floods, while WaterGAP estimates only recharge beneath lakes and wetlands. Therefore, it is best to compare the difference between $R_{g,swb}$ and Rg ($Rg,_{nat}$) of Margat and van der Gun with natural diffuse groundwater recharge $Rg,_{nat}$ of WaterGAP (Table 2.9). For Mexico and Cyprus, WaterGAP estimates are in good accord with estimates from Margat and van der Gun. As already discussed in Döll *et al*. (2014), WaterGAP underestimates groundwater recharge in the North China Plain. Diffuse groundwater recharge in Mexico is twice as high in this study as the independent estimate. For the other four countries, the diffuse groundwater recharge values fit together quite well.

Effects of modelling assumptions on computed indicators

Horizontal groundwater flow between cells as well as capillary rise is not taken into account in WaterGAP. The effect of neglecting these processes on indicators 3.1 (groundwater depletion) and 4.2 (groundwater development stress), however, is considered to be small compared to uncertainties regarding estimated groundwater recharge and abstractions. Furthermore, only one unconfined aquifer is modelled in WaterGAP, meaning that indicators cannot be assigned to individual, three-dimensional aquifer bodies that may overlap.

Table 2.9. Comparison of diffuse groundwater recharge and recharge from surface water bodies (in km³/yr) as modelled by WaterGAP for current conditions with estimates from Margat and van der Gun (2013)

Country / aquifer	WaterGAP			Margat and van der Gun (2013)		
	$R_{g,nat}$ 1)	$R_{g,swb}$ 2)	R_{g} 3)	$R_{g,nat}$ 1)	$R_{g,swb}$ 2)	R_{g} 3)
Iran	41.6	49.7	91.3	36.6	12.7	49.3
Mexico	111.1	25.5	136.6	48	19	67
North China Plain aquifer	10.4	0.4	10.8	28.3	7.6	35.9
United Arab Emirates	0.4	10.8	11.2	≈ 0.02	≈ 0.10	0.12
Saudi Arabia	5.1	8.0	13.1	≈ 0.2	≈ 2.0	2.2
Cyprus	0.49	0.06	0.55	0.27	0.14	0.41

1) *Diffuse groundwater recharge;*
2) *Groundwater recharge from surface water bodies*
3) *Mean groundwater flux including contribution by surface water*

Livestock water use was not taken into account in this study, because for most areas there are no projections available for this sector and livestock water use is mostly small compared to other sectoral water uses. An analysis of consumptive water use of livestock in 2010 showed that values of less than 1 mm/yr occur in most TBAs with the exception of the Belgian-Dutch-German Lowland aquifer system (< 10 mm/yr), the East Ganges River Plain aquifer and the South of outer Himalayas aquifer (both < 5 mm/yr), and the merged Serra Geral/Guaraní aquifer system (< 2 mm/yr). To assess the potential effect of neglecting livestock water use on the current-state indicator 4.2a (net abstractions from groundwater divided by natural groundwater recharge), the country segment-based indicator was re-calculated after adding the total consumptive water use of livestock in 2010 to the net abstractions from groundwater (annual mean 1971-2000). This implies that livestock water use is only satisfied from groundwater and that return flows from the livestock sector are assumed to recharge surface water only. Based on this approach, eight out of 258 country segments would fall into a higher risk class for indicator 4.2a compared with the model run neglecting livestock. These country segments and the associated indicators are listed in Table 2.10. None of the four aquifers with more than 1 mm/yr livestock water use would be affected by a change in risk class if livestock water use had been taken into account because of high groundwater recharge rates or high total water abstractions.

Table 2.10. Country segments with an increase in risk class of the current-state indicator 4.2a (groundwater development stress, including artificial recharge) when livestock water use is considered

TBA_CU	Indicator 4.2a [%] Without livestock	Indicator 4.2a [%] Including livestock	Increase [Percentage points]
AF56_DZA (Algeria)	49.6 (medium)	339.4 (very high)	289.8
AF52_DZA (Algeria)	14.7 (low)	21.5 (medium)	6.8
AF63_TCD (Chad)	-1.5 (very low)	9.2 (low)	10.7
AF5_NAM (Namibia)	1.7 (very low)	2.7 (low)	1.0
AS97_RUS (Russia)	1.4(very low)	2.7 (low)	1.3
AS36_UZB (Uzbekistan)	14.2 (low)	22.1 (medium)	7.9
AS111_MNG (Mongolia)	0.8 (very low)	3.9 (low)	3.1
16N_MEX (Mexico)	1.1 (very low)	3.1 (low)	2.0

Classification of GW development stress: 0-2 %: very low; 2-20 %: low; 20-50 %: medium; 50-100 %: high; > 100 %: very high

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Chapter 3

Indicator-based assessment of Transboundary Aquifers

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Chapter Citation: Merla, A., Nijsten, G.J., Döll P., Riedel, C., Burchi, S., Dumont, A., Aureli, A. (2016). Chapter 3: Indicator-based assessment of Transboundary Aquifers. In UNESCO-IHP and UNEP (2016). Transboundary Aquifers and Groundwater Systems of Small Island Developing States Status and Trends. United Nations Environment Programme, Nairobi, pp. 45-100.

3. Indicator-based assessment of Transboundary Aquifers

3.1. Current-state indicators

These indicators are related to conditions and processes as currently present or occurring. Some of them capture the physical and chemical characteristics of the aquifers, others focus on human features such as socio-economic and legal- institutional attributes. They include indicators that are:

(i) time-independent or weakly time-dependent, meant to contribute to a general aquifer characterisation, and hence in principle assessed only once, during the baseline assessment, although they may be subject to subsequent correction if better data become available;

(ii) time-dependent features that reveal changes that are relevant for defining the priorities of investing in activities that aim to promote the joint management of the individual transboundary aquifers. Assessing these indicators has to be repeated periodically after the baseline assessment to establish trends and impacts of global changes and human interventions.

What follows relies essentially on WaterGAP modelling and the results achieved for the ten core indicators (Table 2.3) for TBAs larger than 20 000 km^2. Data from the Global Inventory – albeit far from providing a full coverage for all TBAs larger than 5 000 km^2 – allowed filling in of indicators related to water quality and to governance (indicators not covered by WaterGAP) in many national segments and a small number of complete TBAs, and adding information on other indicators.

3.1.1. Defining or constraining the value of aquifers and their potential functions

Mean annual groundwater recharge (Core Indicators 1.1, 1.2)

Groundwater recharge is replenishment of the groundwater of an aquifer. It is usually expressed as an average depth in millimetres of water per year over the total extent of the aquifer, similar to the way precipitation is reported. Reliability of groundwater recharge data is controlled, in particular, by the identification of the prevailing recharge mechanisms and the accuracy of delineation of transboundary aquifers recharge areas.

The mean annual groundwater recharge indicator in TWAP represents current conditions and aims to be a long-term average.

Three indicators were calculated:

Indicator 1.1 – Mean annual groundwater recharge including artificial recharge (Figures 3.1, 3.4, and 3.5)

This indicator is the sum of natural groundwater recharge including point recharge from surface water bodies, and artificial recharge from irrigation (return flows). In WaterGAP, this artificial recharge is equal to simulated water withdrawals from groundwater (WWgw) minus net groundwater abstractions (NAg). Net abstractions are computed as the difference between water withdrawals from the specific source and the return flows from water use to the source. Net abstractions can become negative if return flows exceed water withdrawals (for example in the case of irrigation from surface water). For NAg, this can only occur in the case of irrigation from surface water.

Indicator 1.1a – Mean annual natural groundwater recharge (Figure 3.2)
Natural mean annual groundwater recharge was calculated as the sum of natural groundwater recharge including point recharge from surface water bodies.

Indicator 1.2 – Mean annual per capita groundwater recharge, including artificial recharge (Figures 3.3, 3.6, and 3.7)
The mean annual groundwater recharge per capita was calculated as total groundwater recharge in m³ (including recharge from surface water bodies and return flows) divided by the population in 2010.

Key findings

Highest groundwater recharge rates exceeding 300 mm/yr are found in humid areas including the Amazonas aquifer, the Cuvette aquifer in Central Africa, the Indus River Plain aquifer, the East Ganges River Plain aquifer and the Khorat Plateau aquifer extending over Laos and Thailand. TBAs characterized by low recharge rates between 2 and 20 mm/yr are the Northwest Sahara Aquifer System and the two merged aquifers AS126_129 and AS131 located on the Arabian Peninsula. Based on the aggregation over TBAs, no aquifers were identified with very low groundwater recharge rates below 2 mm/yr. When the aggregation level is reduced to country segments, however, several country segments in arid regions are revealed as receiving very low groundwater recharge, namely the Nubian Sandstone Aquifer System in Chad, the northern fractions of the lake Chad Basin aquifer, the Taoudeni Basin aquifer and the Irhazer-Illuemeden Basin aquifers in Algeria, and the Uzbek part of the Syr Darya aquifer.

Not accounting for return flows from irrigation (1.1a), the differences with indicator 1.1 are most evident in the major irrigation areas of the world including the East Ganges River Plain (East Ganges River Plain aquifer), the Indus River Plain (Indus River Plain aquifer), and the Nile delta (Nubian Sandstone Aquifer System. Modelled return flows over the Indus River Plain aquifer in Pakistan and India account for about 70 per cent and 40 per cent of total groundwater recharge (including induced recharge). Over the Nubian Sandstone Aquifer System, return flows from irrigation were computed at 44 per cent (Egypt) and 38 per cent (Sudan) of total groundwater recharge. Over the East Ganges River Plain aquifer, 27 per cent of total groundwater recharge is contributed by return flows.

As shown by indicator 1.2[21], low per-capita groundwater resources of less than 1 000 m³ per capita per year are not only limited to TBAs in arid regions (Tawil Quaternary Aquifer System, Nubian Sandstone Aquifer System), but are also present in humid areas because of high population densities (Belgian-Dutch-German Lowland aquifer system, East Ganges River Plain aquifer).

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[21] Values for indicator 1.1 and 1.2 in the Global Inventory, when available, are somewhat lower.

Figure 3.1. Current-state indicator 1.1 Mean annual groundwater recharge under current conditions including artificial recharge from irrigation in mm/yr per a) grid cell, b) TBA-country segments, c) TBA.

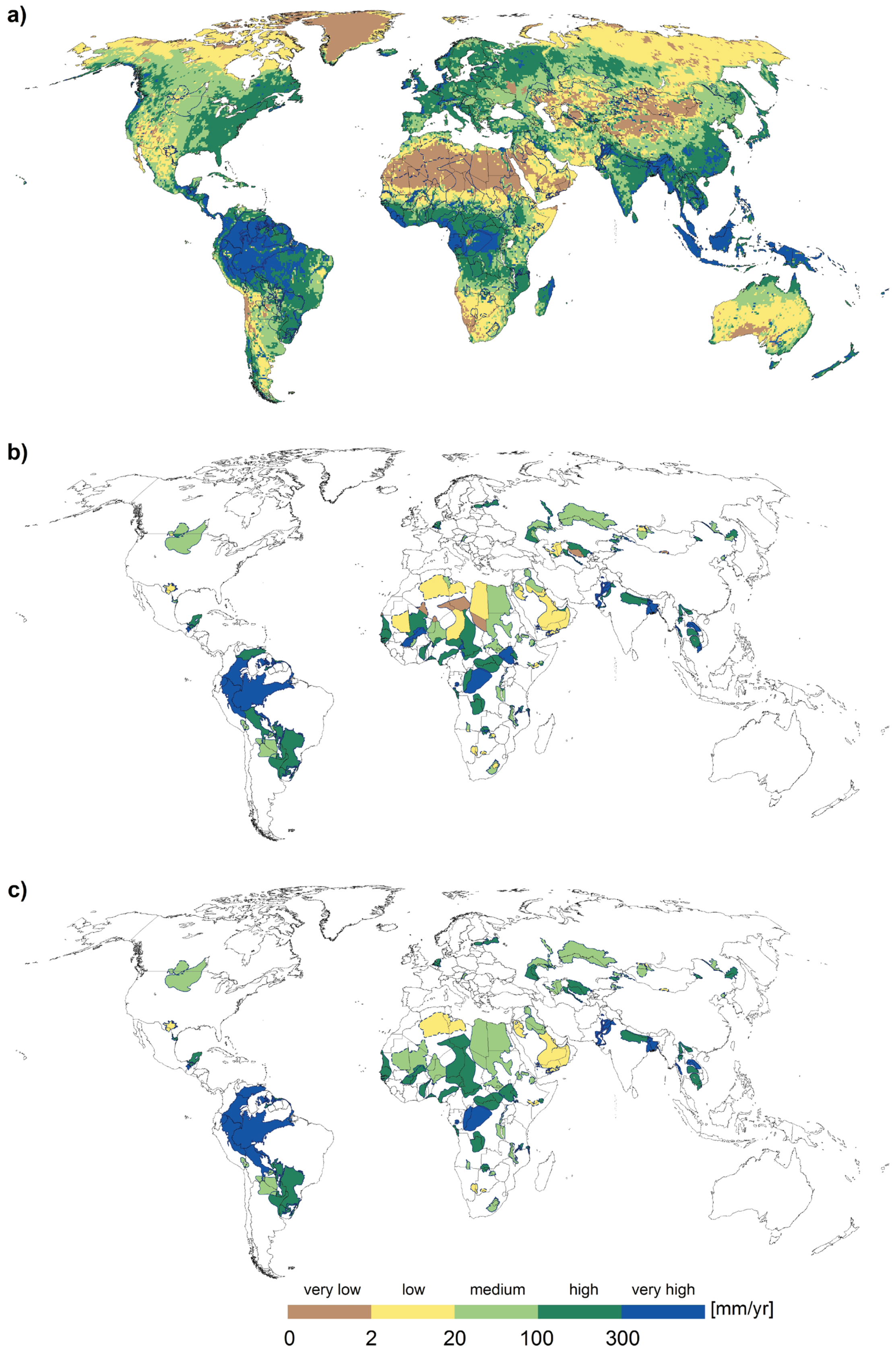


Figure 3.2. Current-state indicator 1.1a Mean annual groundwater recharge (natural) under current conditions in mm/yr per a) grid cell, b) TBA-country segments, c) TBA.

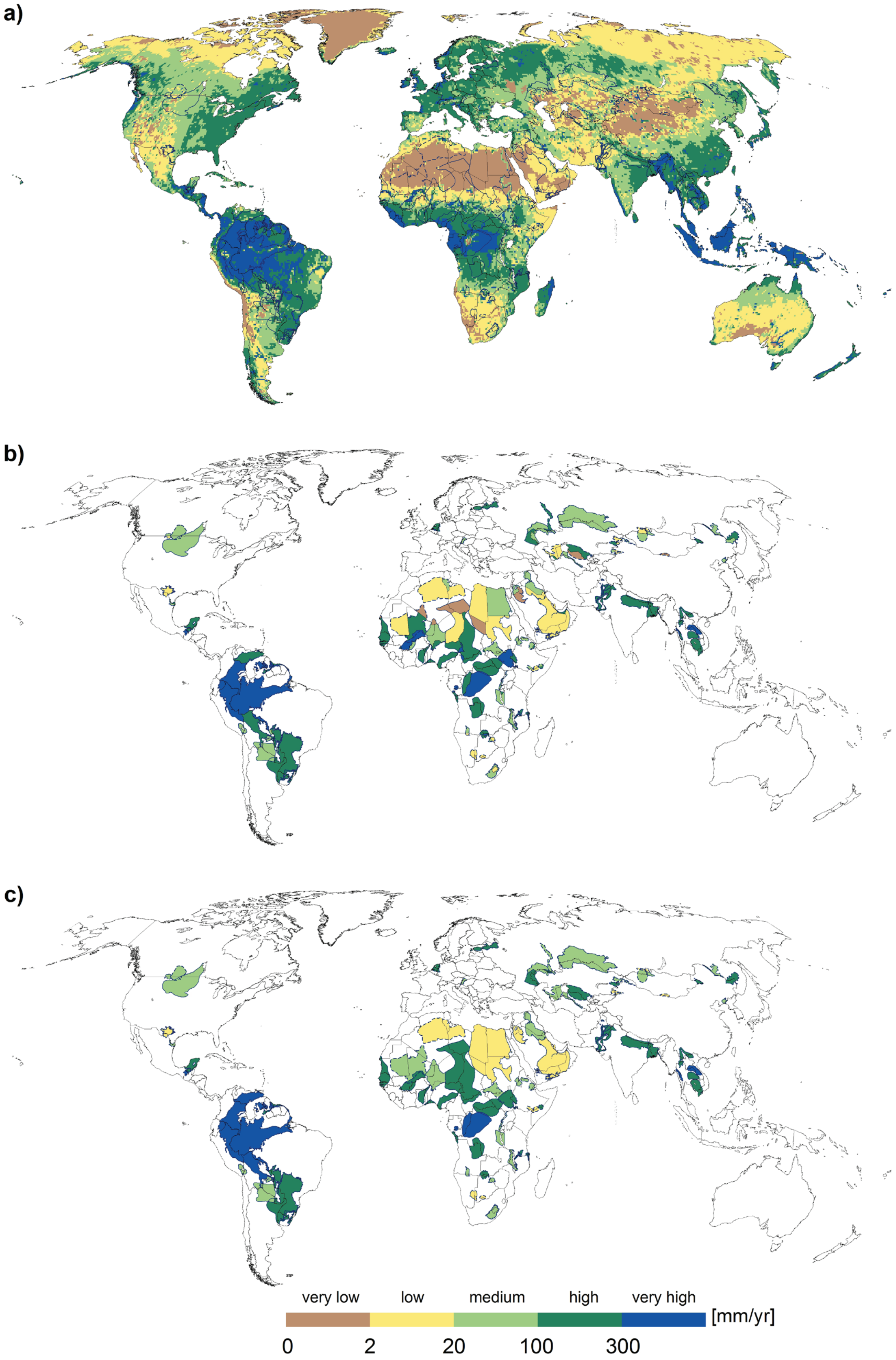


Figure 3.3. Current-state indicator 1.2 Mean annual per-capita groundwater recharge under current conditions including artificial recharge from irrigation in m³ per capita per year a) grid cell, b) TBA-country segments, c) TBA.

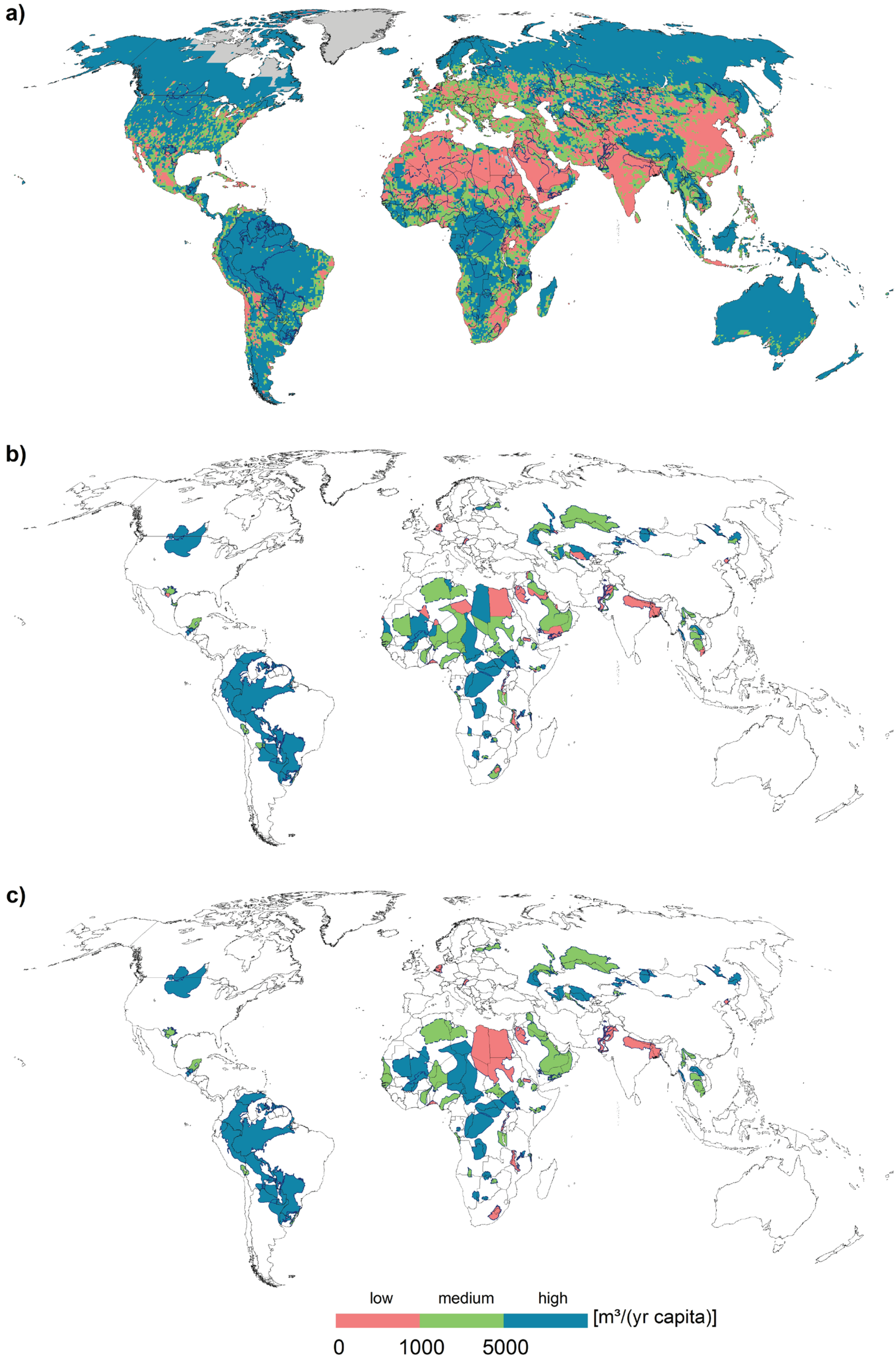


Figure 3.4. Indicator 1.1 – Recharge: distribution of TBA country segments per indicator category, based on Global Inventory. Top diagram: distribution at global scale by no. of country segments, and percentage of surface area and population (as per cent of total TBAs area / population). Bottom: distribution per continent. Recharge is expressed in mm per year.

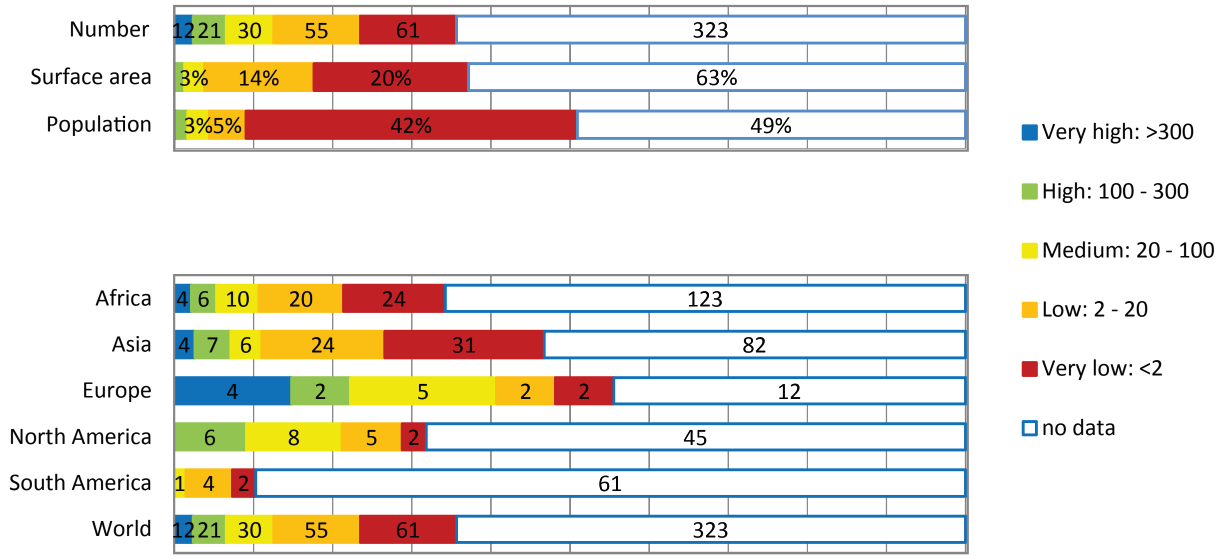


Figure 3.5. Indicator 1.1 – Recharge: distribution of TBA country segments per indicator category, based on WaterGAP. Top diagram: distribution at global scale by no. of country segments, and percentage of surface area and population (as per cent of total TBAs area / population). Bottom: distribution per continent. Recharge is expressed in mm per year.

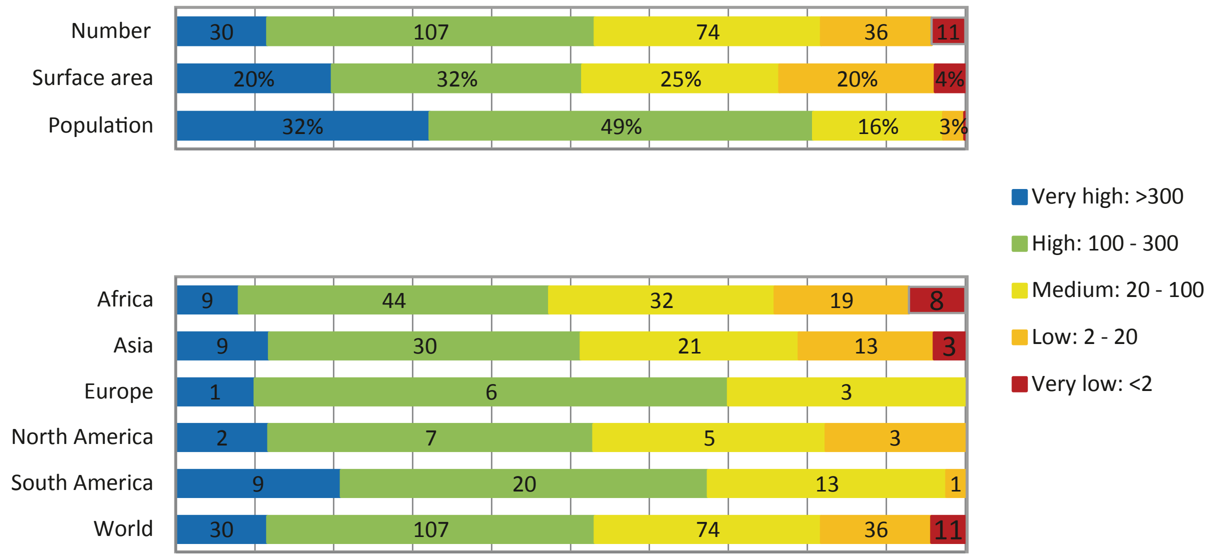


Figure 3.6. Indicator 1.2 – Recharge per capita: distribution of TBA country segments per indicator category, based on Global Inventory. Top diagram: distribution at global scale by no. of country segments, and percentage of surface area and population (as per cent of total TBAs area / population). Bottom: distribution per continent. Recharge per capita is expressed in m³/year/capita.

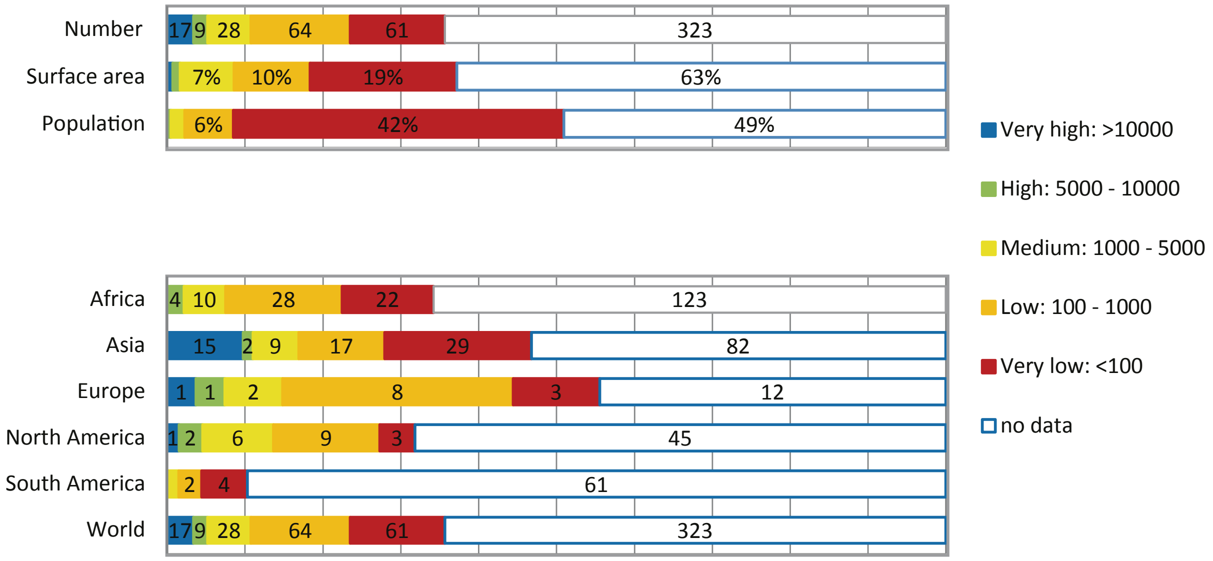
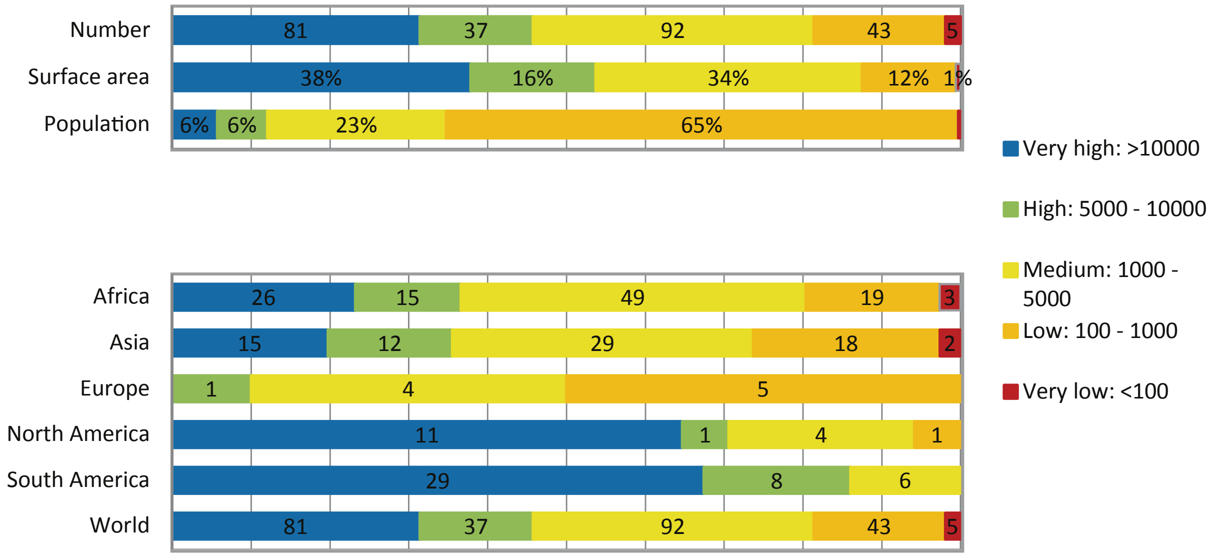


Figure 3.7. Indicator 1.2 – Recharge per capita: distribution of TBA country segments per indicator category, based on WaterGAP. Top diagram: distribution at global scale by no. of country segments, and percentage of surface area and population (as per cent of total TBAs area). Bottom: distribution per continent. Recharge per capita is expressed in m³/year/capita.



Background groundwater quality (Core Indicator 1.3)

Indicator 1.3 – Natural background groundwater quality

For the purposes of TWAP, this is defined as the percentage of the aquifer area where groundwater natural quality satisfies local drinking water standards. Data for the computation of this indicator (Global Inventory) are scarce - available only for 125 country segments, including 5 complete TBAs – and do not allow any global-scale consideration. It can be noted however, that very low natural quality (< 20 per cent of the aquifer area) coincides with TBAs highly impacted by irrigation return flows in densely populated areas with low to medium natural recharge, for example the Nubian, Indus, and Pre-Caspian TBAs (Figure 3.5).

Figure 3.8. Current-state indicator 1.3 – Natural background quality (in % of surface with good quality) by TBA country segments.

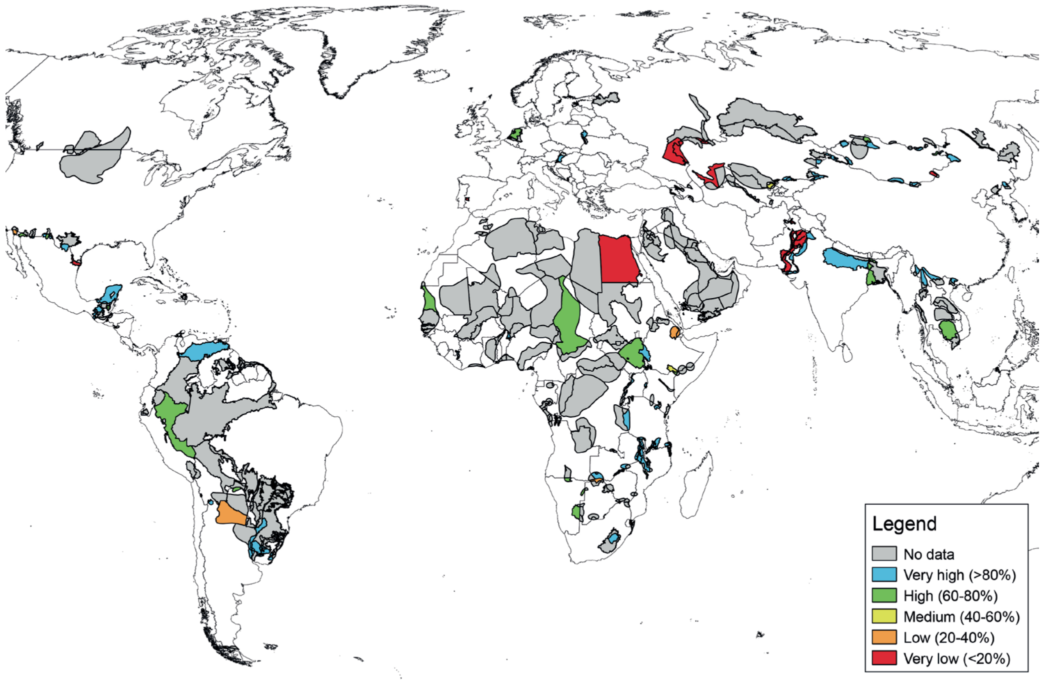



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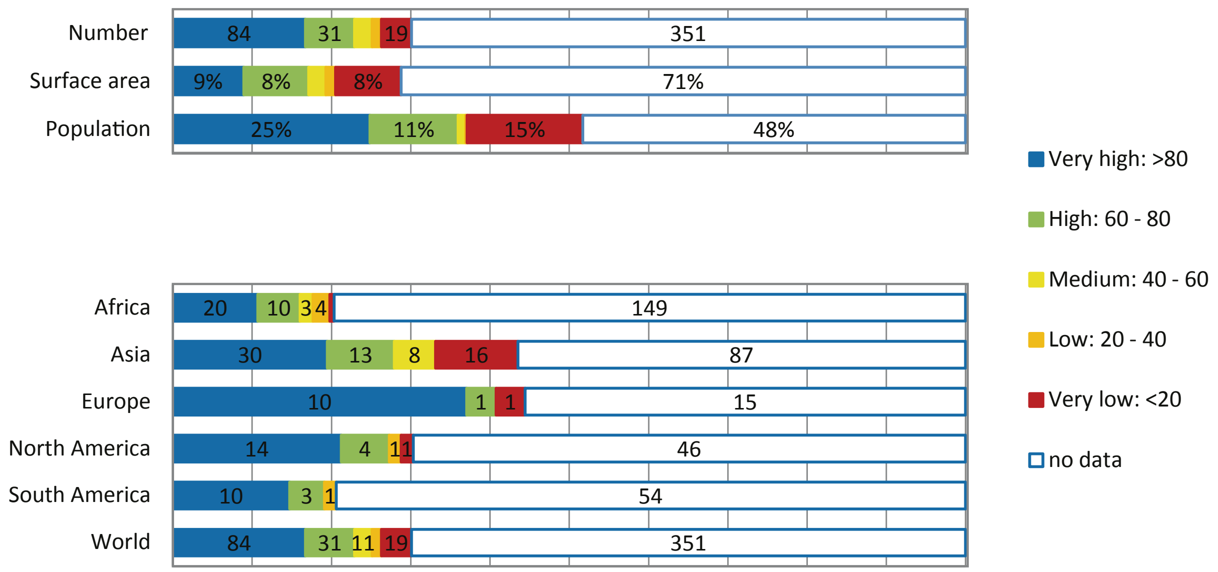
Figure 3.9. Indicator 1.3 – Natural background quality: distribution of TBA country segments per indicator category, based on Global Inventory.
Top diagram: distribution at global scale by no. of country segments, and percentage of surface area and population (as per cent of total TBAs area / population). Bottom: distribution per continent. Natural background quality is expressed in %: percentage of surface area with good quality.



Additional Indicators 1.4, 1.5, 1.6

Like Core Indicator 1.3, these additional indicators, which complete the picture of the factors that define aquifer potentialities for human use, have been computed for only the limited number of TBAs / country segments for which data are available in the Global Inventory.

Indicator 1.4 – Aquifer buffering capacity

The buffer capacity of groundwater systems offers unique opportunities for overall reduction of risk and uncertainty regarding water availability, both now and in the future. Changes to the availability and quality of groundwater proceed very slowly compared with those of the components of the water cycle that have smaller mean residence times. The computation of Indicator 1.4 – defined as the ratio between volume stored and long-term mean groundwater recharge (equivalent to mean residence time of groundwater) – is available for only 125 country segments and 7 complete TBAs.

Aquifer buffering capacity can be used as a simply proxy for an aquifer's resilience to climatic variability can be due to climate change, but also to seasonable variability. Aquifers with a high buffering capacity (high volume of water in storage compared to the annual amount of recharge) are much more resilient to climate variability than aquifers with low buffering capacity.

Key findings

High residence times of groundwater, over 100 years to more than >1000 years, is reported for a number of country segments of TBAs in the Sahel and Saharan Africa, Central and South Asia, where aquifer capacity to mitigate the effects of prolonged droughts is highly valuable.

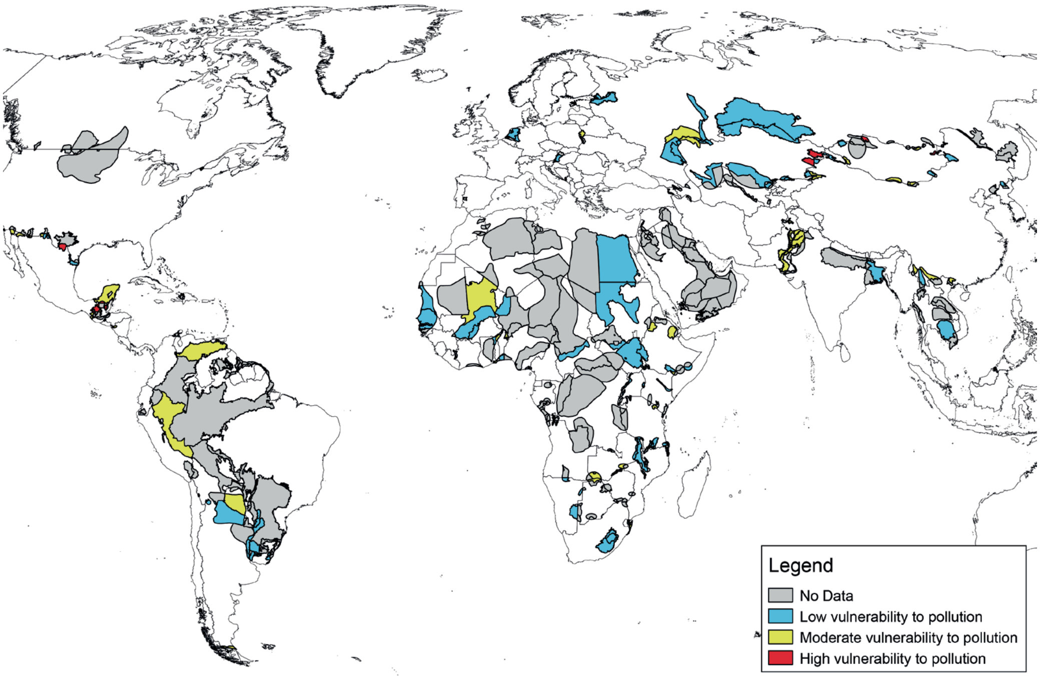
Indicator 1.5 – Aquifer vulnerability to climate change

It is defined as the extent of expected groundwater budget regime change in response to change in climate, and has been computed for 111 country segments and 7 full TBAs. Scarce data show correlation between lack of aquifer confinement and rapid response to climate change and variability in all regions.

Indicator 1.6 – Aquifer vulnerability to pollution (Figure 3.10)

This natural property of a groundwater system depends on the sensitivity of the system to human impacts. Data on this complex indicator are very scarce (only 10 per cent of country segments). Most country segments of large TBAs show low vulnerability to anthropogenic pollution.

Figure 3.10. Current-state indicator 1.6 - Aquifer vulnerability to pollution by TBA country segments .



3.1.2. Role and importance of groundwater for humans and the environment

The indicators of human and environmental dependence on groundwater are based on social, economic and ecology-related data expressing population, agricultural, industrial and ecological dependence on groundwater. Two indicators have been adopted: a core indicator of human dependence on groundwater, and an additional indicator of ecosystem dependence on groundwater.

Human dependence on groundwater (Core Indicator 2.1 and Additional Indicators 2.2, 2.3, 2.4)

Four indicators have been calculated (WaterGAP - all TBAs > 20 000 km^2):

Indicator 2.1 – Human dependence on groundwater - Core Indicator (Figures 3.11, 3.15, and 3.16)

Core indicator 2.1 was computed as the percentage of annual groundwater abstraction in total water abstraction for all human water uses.

Indicator 2.2 – Human dependence on groundwater for domestic water supply – Additional (Figures 3.12 and 3.17)

Calculated as percentage of groundwater in total water abstraction for domestic water use, applying values for the year 2010.

Indicator 2.3 – Human dependence on groundwater for agricultural water supply - Additional (Figure 3.13 and 3.18)
Calculated as percentage of groundwater in total water abstraction for agricultural water use. WaterGAP only takes irrigation into account, and excludes water used for watering cattle. Climate-dependent irrigation water use is based on the climate period 1971-2000 and irrigated areas in 2005.

Indicator 2.4 – Human dependence on groundwater for industrial water supply - Additional (Figure 3.14 and 3.19)
Calculated as percentage of groundwater in total water abstraction for industrial water use, applying values in 2010.

Key Findings

According to modelling results, 193 out of 258 country segments have a Very Low to Low dependence on groundwater (0-40 per cent), while in 39 country segments the dependence on groundwater is classified as medium (40-60 per cent).

In 22 country segments, mostly in Africa, groundwater abstractions account for 60 to 80 per cent of total water abstractions. The highest fractions of groundwater use, of about 90 per cent, were computed for the Libyan part of the Lake Chad Basin aquifer and the Amu-Darya aquifer in Uzbekistan. Note the effect of spatial aggregation on this indicator, for example in Saudi Arabia. While the majority of 0.5° grid cells show a very high fraction of groundwater use, the low TBA and country segment values result from a few coastal grid cells with high population and water use not from groundwater.

High to very high groundwater fractions in the domestic sector were identified for the Península de Yucatán-Candelaria-Hondo aquifer (Mexico), the Amu-Darya aquifer (Uzbekistan), the Keta/Dahomey/Cotier basin aquifer (Benin, Togo), and the country segments located in Libya.

Groundwater fractions in the irrigation sector are highest in TBAs extending over Libya and Algeria, the Taoudeni Basin aquifer in Mauritania, the Kalahari Karoo Basin/Stampriet Artesian Aquifer System in Namibia, and TBAs in Saudi Arabia and Oman (e.g. Tawil Quaternary Aquifer System, Wajid Aquifer System, Neogene Aquifer System).

A high degree of human dependence on groundwater for industrial purposes was estimated in Mongolia (Delger River aquifer, Shishhid River aquifer), the Volta Basin aquifer (Burkina Faso, Benin, and Togo), the Keta/Dahomey/Cotier basin aquifer in Benin, and the Gedaref aquifer in Ethiopia.

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Figure 3.11. Current-state indicators 2.1 – Human dependance on groundwater: percentage of groundwater in total water abstraction for all human water uses in 2010 per a) grid cell, b) TBA Country Segments, c) TBA.

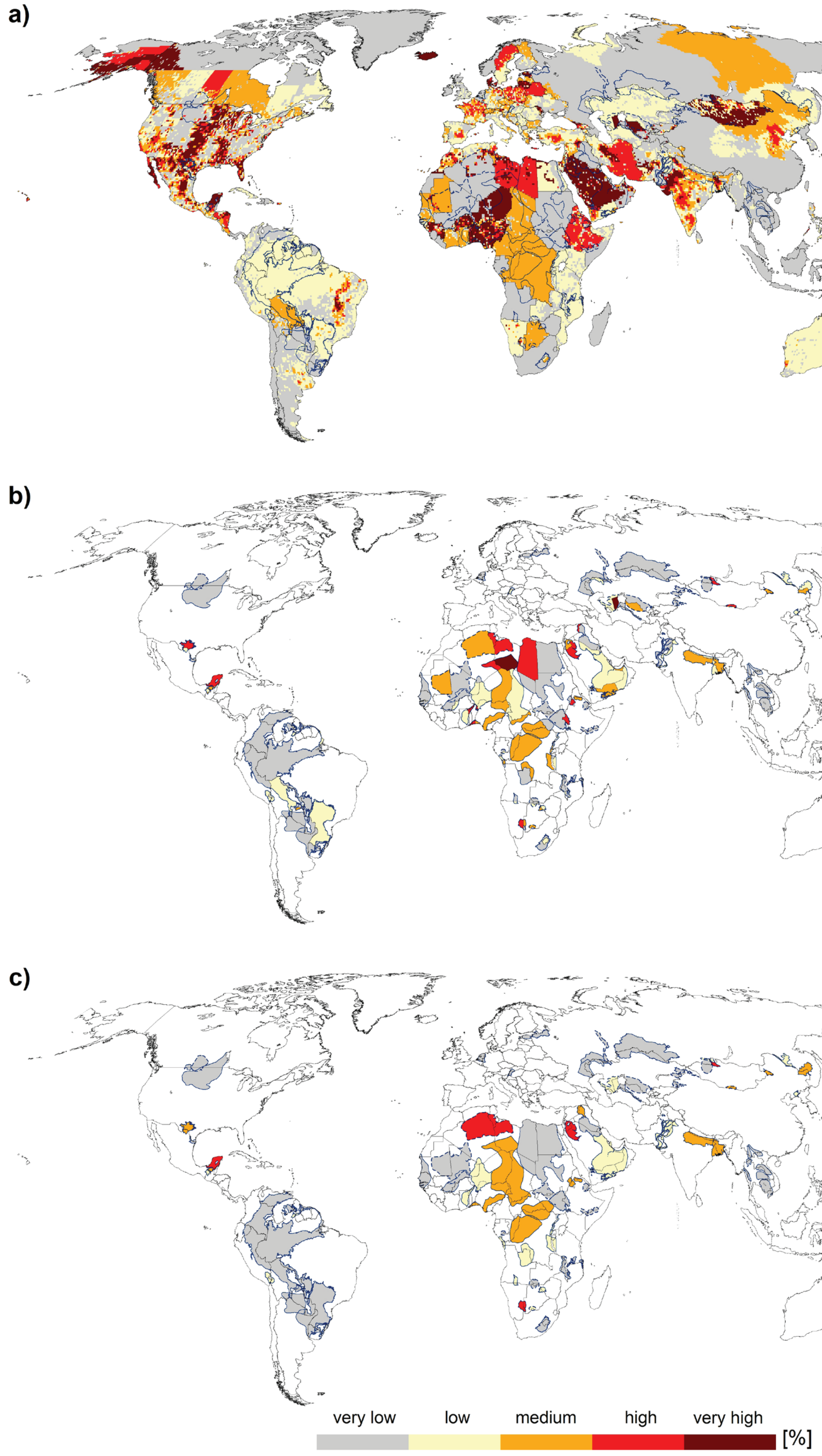


Figure 3.12. Current-state indicator 2.2 – Human dependence on groundwater for domestic water supply: percentage of groundwater in total water abstraction for domestic water use in 2010 per a) grid cell, b) TBA country segments, c) TBA.

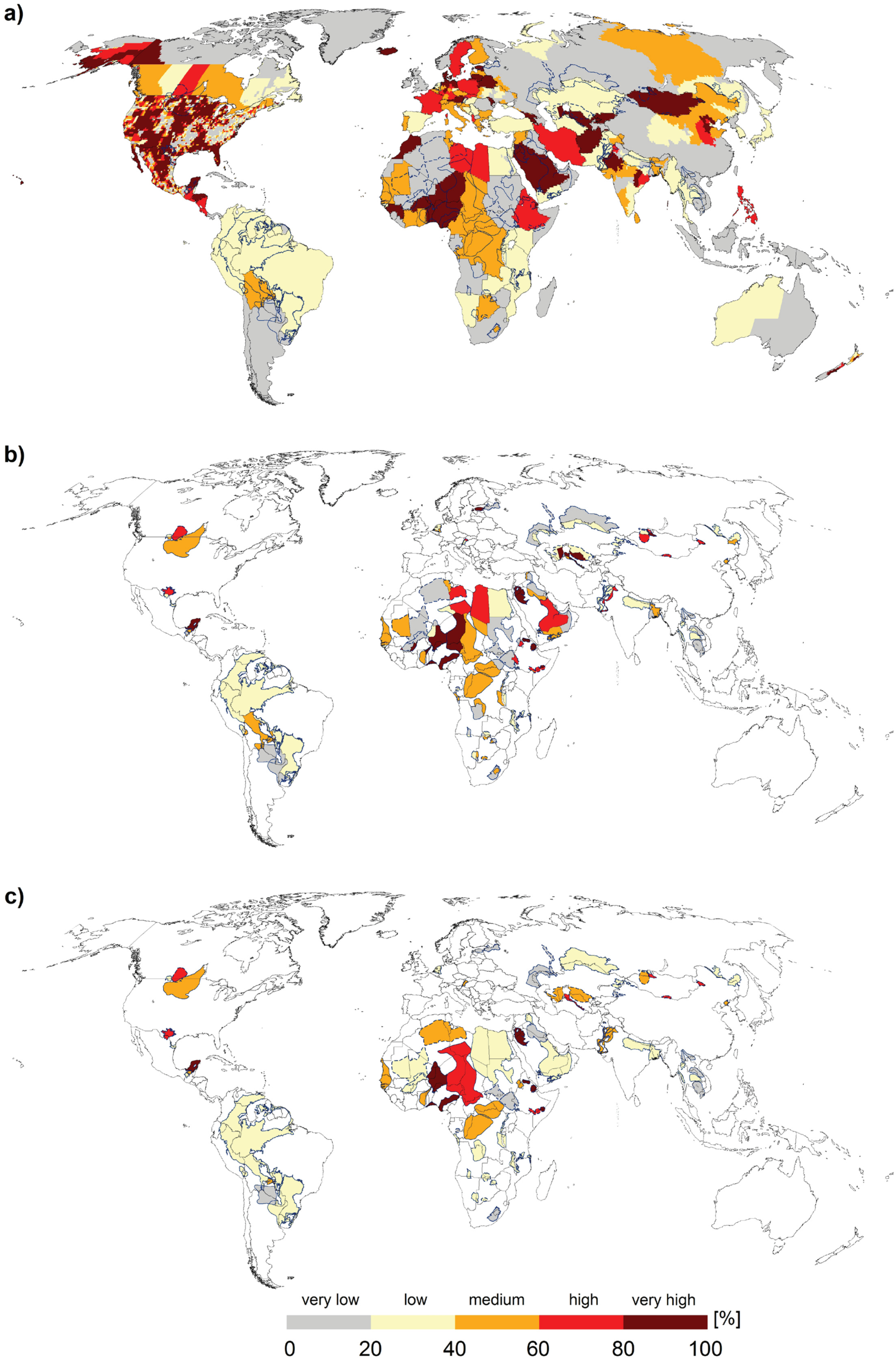


Figure 3.13. Current-state indicator 2.3 – Human dependence on groundwater for irrigation : percentage of groundwater in total water abstraction for irrigation in 2010 per a) grid cell, b) TBA Country Segments, c) TBA.

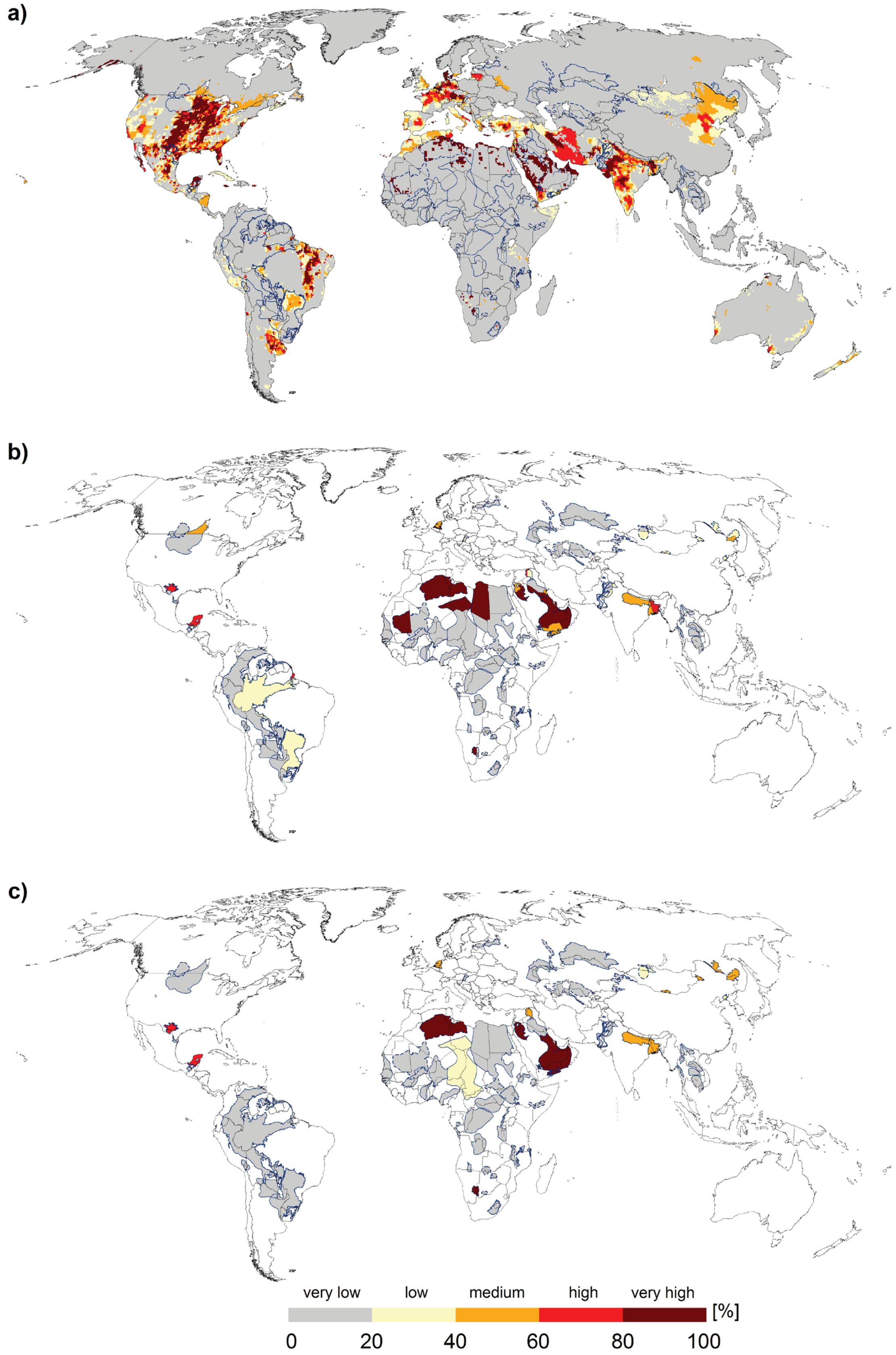


Figure 3.14. Current-state indicator 2.4 – Human dependence on grounwater for industrial water supply in percentage of groundwater in total water abstraction for industrial water use in 2010 per a) grid cell, b) TBA Country Segments, c) TBA.

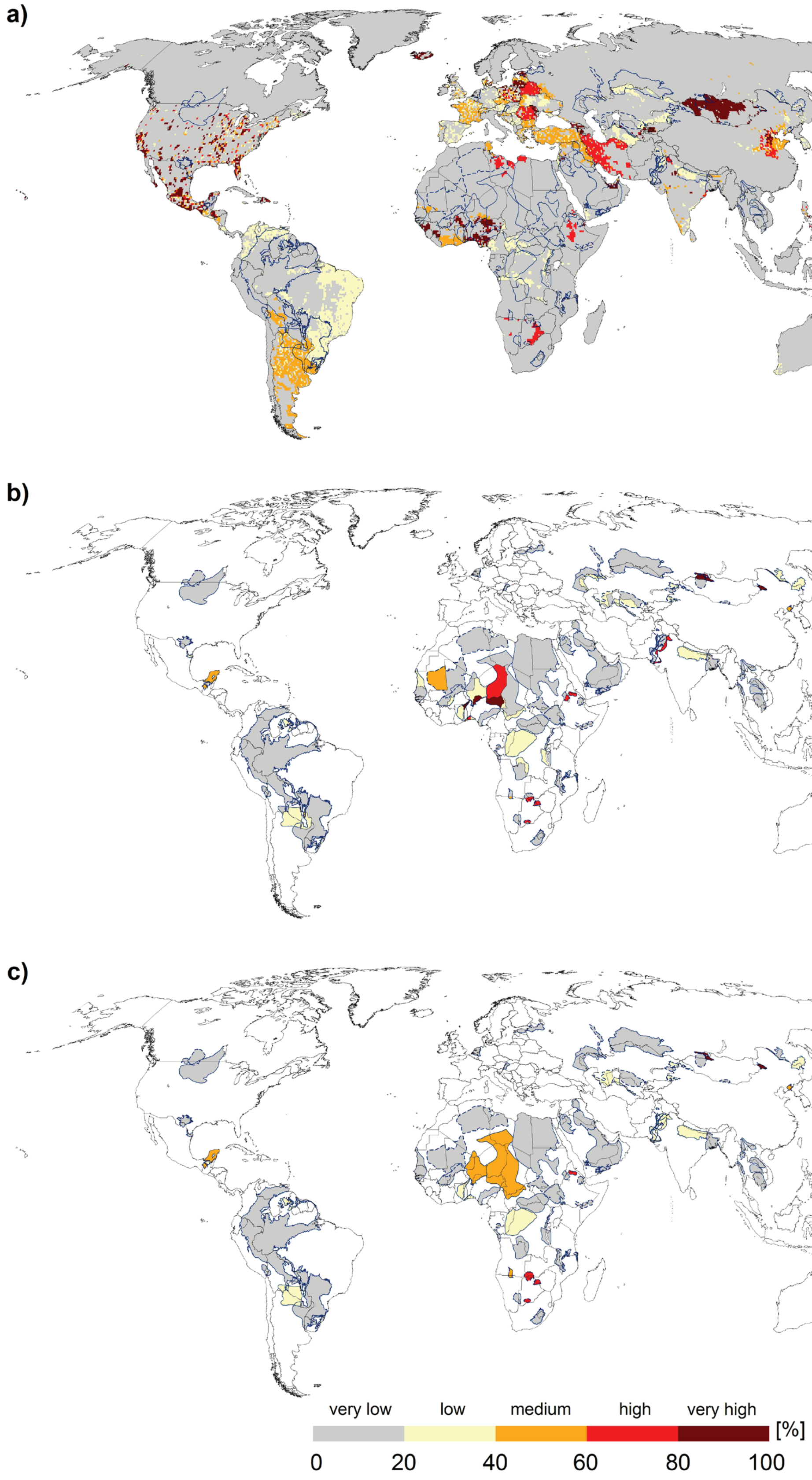


Figure 3.15. Indicator 2.1 – Human dependence on groundwater: distribution of TBA country segments per indicator category, based on Global Inventory.
Top diagram: distribution at global scale by no. of country segments, and percentage of surface area and population (as per cent of total TBAs area / population). Bottom: distribution per continent. Human dependence on groundwater is expressed in %: percentage of groundwater abstraction in total water abstraction.

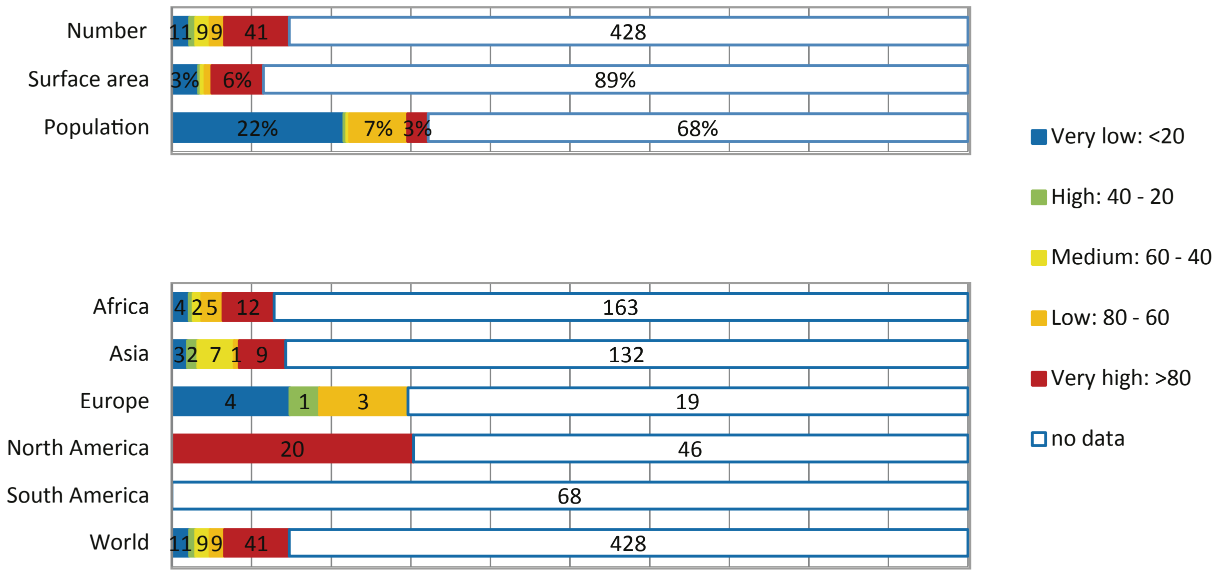


Figure 3.16. Indicator 2.1 – Human dependence on groundwater: distribution of TBA country segments per indicator category, based on WaterGAP.
Top diagram: distribution at global scale by no. of country segments, and percentage of surface area and population (as per cent of total TBAs area / population). Bottom: distribution per continent. Human dependence on groundwater is expressed in %: percentage of groundwater abstraction in total water abstraction.

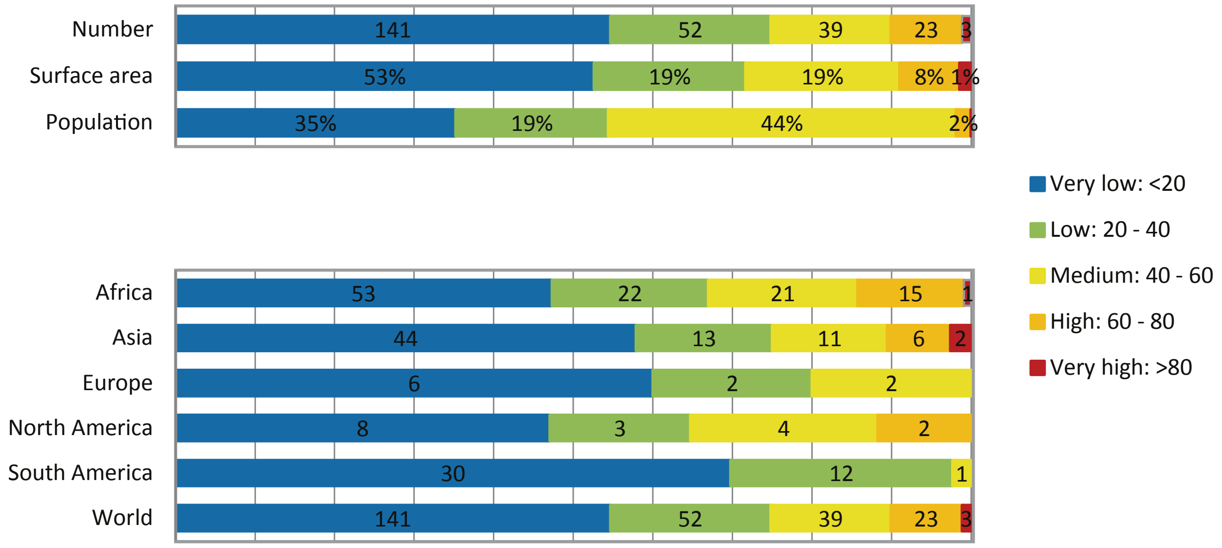


Figure 3.17. Indicator 2.2 – Human dependence on groundwater for domestic water supply: distribution of TBA country segments per indicator category, based on WaterGAP.
Top diagram: distribution at global scale by no. of country segments, and percentage of surface area and population (as per cent of total TBAs area / population). Bottom: distribution per continent. Human dependence on groundwater is expressed in %: percentage of groundwater abstraction in total water abstraction.

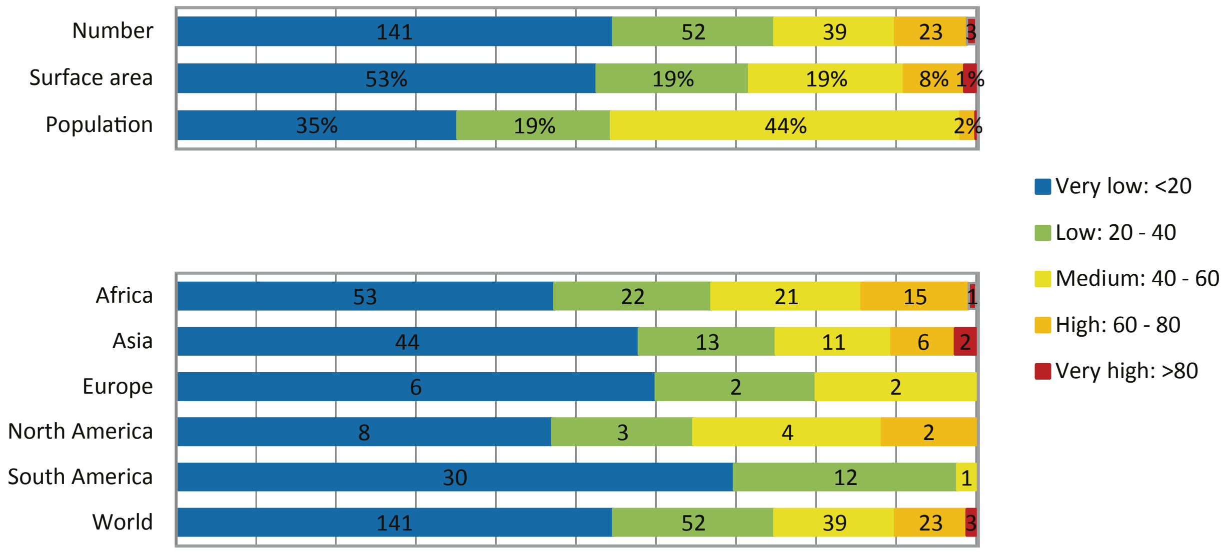


Figure 3.18. Indicator 2.3 – Human dependence on groundwater for agricultural water supply: distribution of TBA country segments per indicator category, based on WaterGAP.
Top diagram: distribution at global scale by no. of country segments, and percentage of surface area and population (as per cent of total TBAs area / population). Bottom: distribution per continent. Human dependence on groundwater is expressed in %: percentage of groundwater abstraction in total water abstraction.

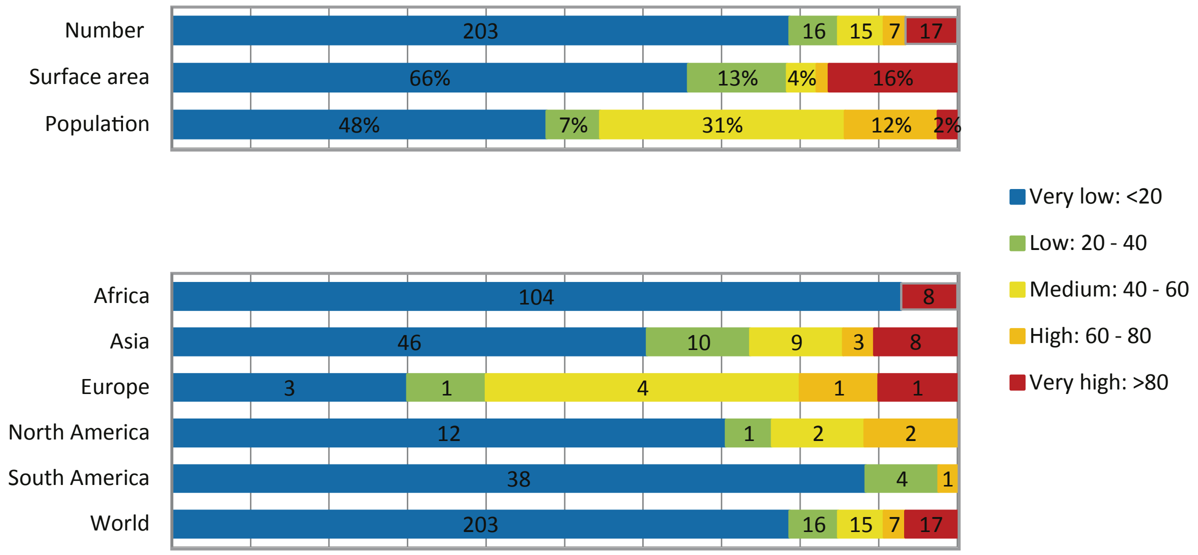
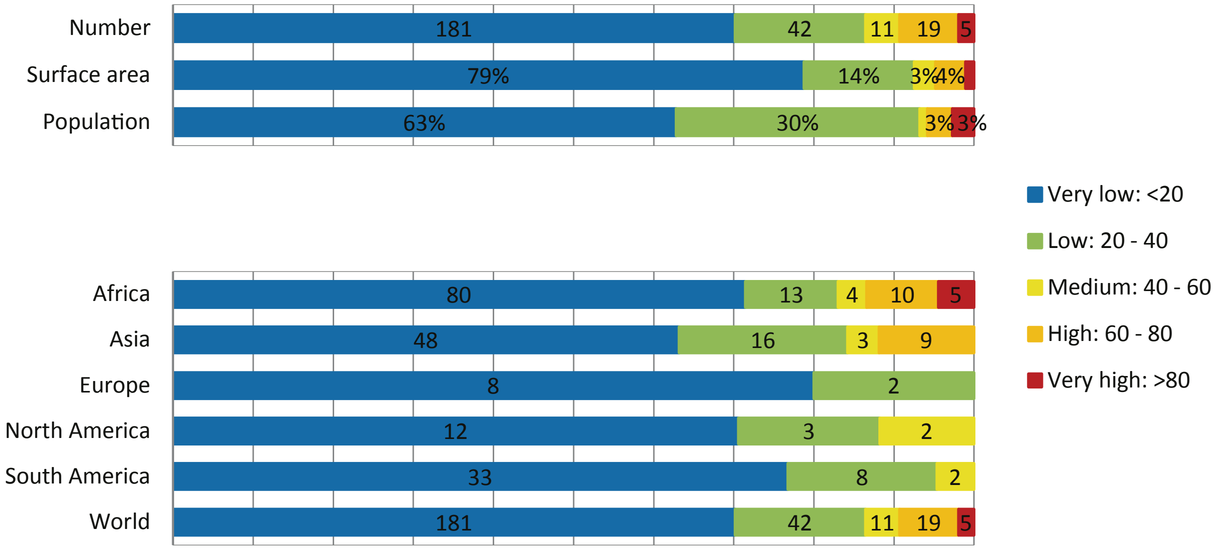


Figure 3.19. Indicator 2.4 – Human dependence on groundwater for industrial water supply: distribution of TBA country segments per indicator category, based on WaterGAP.
Top diagram: distribution at global scale by no. of country segments, and percentage of surface area and population (as per cent of total TBAs area / population). Bottom: distribution per continent. Human dependence on groundwater is expressed in %: percentage of groundwater abstraction in total water abstraction.



Additional Indicators 2.5, 2.6

Indicator 2.5 – Ecosystem dependence on groundwater

This additional indicator is defined as known extent of groundwater dependent ecosystems or percentage of the aquifer's area where the aquifer has a phreatic water level shallower than 5 m below surface. Data derived from the Global Inventory are very scarce, covering only 75 country segments and one full TBA.

This low level of response to questionnaires does not allow any conclusion to be drawn, other than noting the low level of recognition within the national expert community of the role of groundwater in sustaining freshwater ecosystems.

Indicator 2.6 – Prevalence of springs

Additional indicator 2.6 is defined as total annual groundwater discharge by springs, divided by mean annual groundwater recharge. Since springs are very sensitive to the impacts of climate and human actions (withdrawals), 2.6 might provide a meaningful indicator of such changes. However, limited responses, covering only 79 country segments, do not allow any conclusive consideration.

3.1.3. Changes in Groundwater Status

Groundwater depletion (Core indicator 2.6)

Indicator 3.1 – is defined as observed current rate of long-term progressive decrease of groundwater storage (accompanied by steadily declining ground¬water levels), expressed as an equivalent depth of water averaged over the aquifer. It represents the mean annual change in groundwater storage in mm/yr. This indicator has been calculated using WaterGAP for all TBAs over 20,000 km^2. The Global Inventory provides data for only 20 per cent of country segments for TBAs over 5,000 km^2, and 10 full TBAs (Figures 3.20, 3.21, and 3.22).

Key findings

Figure 3.20 shows that groundwater depletion rates averaged over TBAs are very low (less than 2 mm/yr) in most regions of the world. Groundwater depletion rates of more than 10 mm/yr occur in the Neogene Aquifer System in Syria and Iraq, the south of the outer Himalayas aquifer in India and Nepal, and the Indus River Plain aquifer in India and Pakistan. Focusing on the country segment level, the groundwater depletion rate increases to 53 mm/yr (high) in the Syrian part of the Neogene Aquifer System and to 28 mm/yr (medium) in the Indian part of the Indus River Plain aquifer. A comparison of aggregated and grid-based results reveals that most TBAs are located outside the major groundwater depletion regions of the world. Furthermore, low groundwater depletion rates in, e.g. western Africa or the Netherlands can be attributed to natural decadal precipitation trends superimposed on human-driven groundwater depletion.

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Figure 3.20. Current-state indicator 3.1 – Groundwater depletion: mean annual change in groundwater storage for 2000-2009, expressed as an equivalent depth of water divided by area of a) grid cell, b) TBA Country Segments, c) TBA

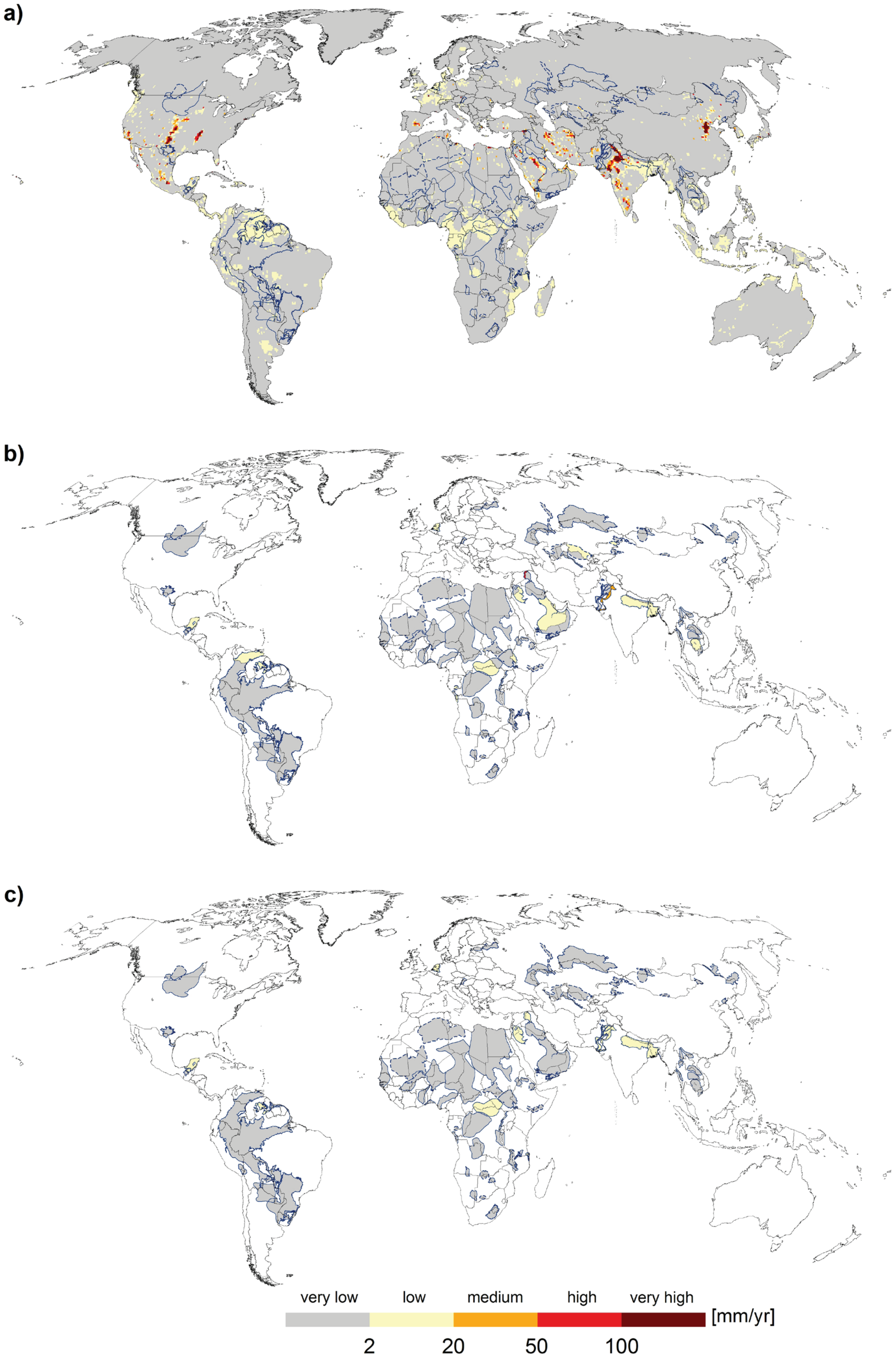


Figure 3.21. Indicator 3.1 – Groundwater depletion: distribution of TBA country segments per indicator category, based on Global Inventory.
Top diagram: distribution at global scale by no. of country segments, and percentage of surface area and population (as per cent of total TBAs area / population). Bottom: distribution per continent. Groundwater depletion is expressed in mm/year.

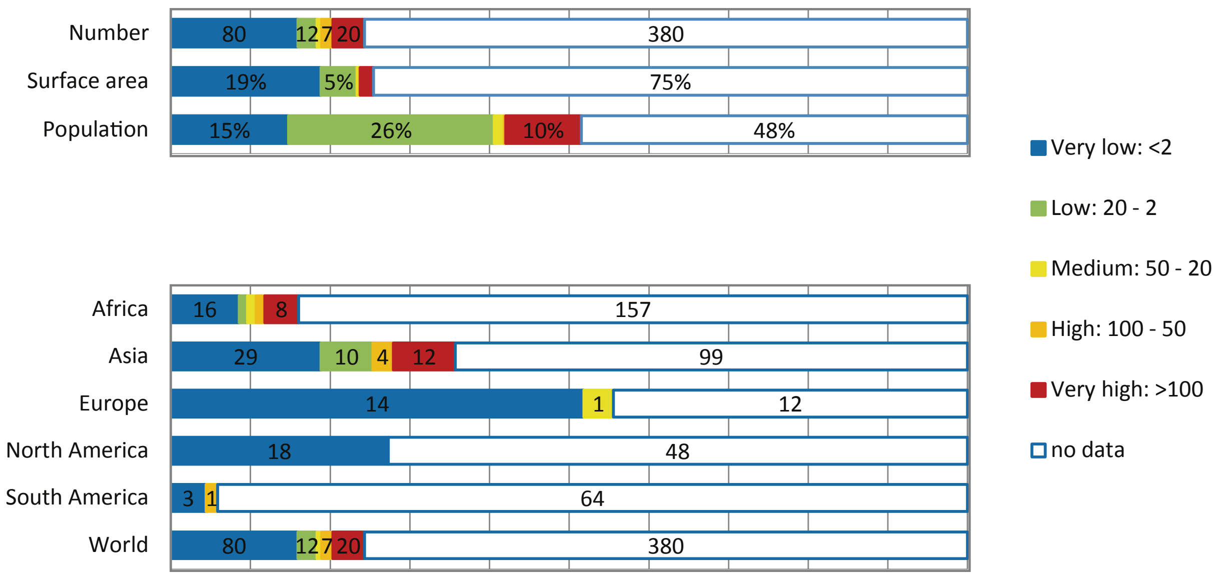
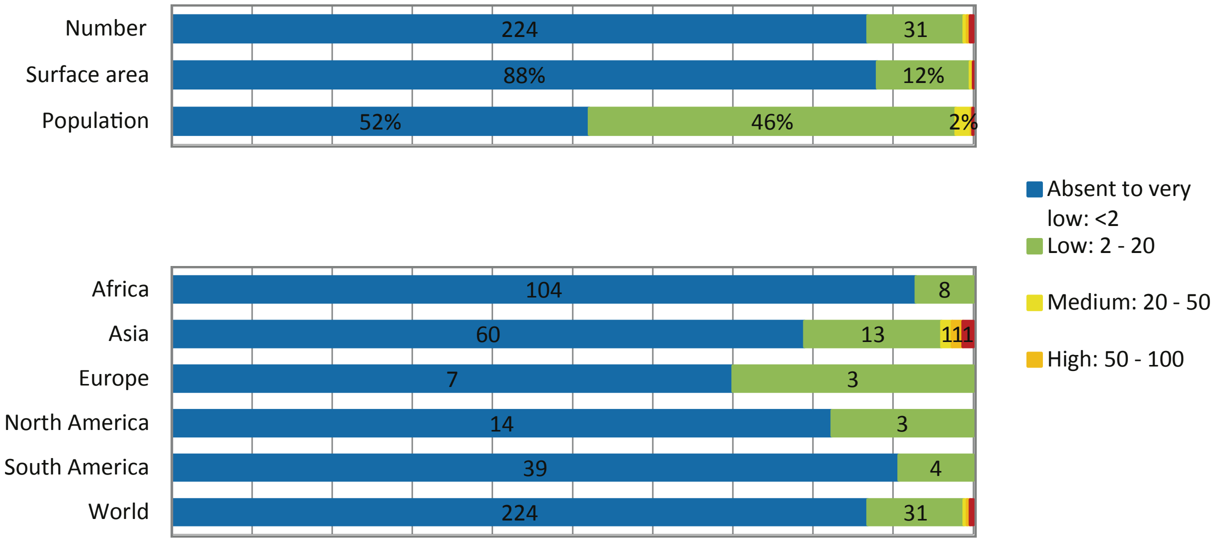


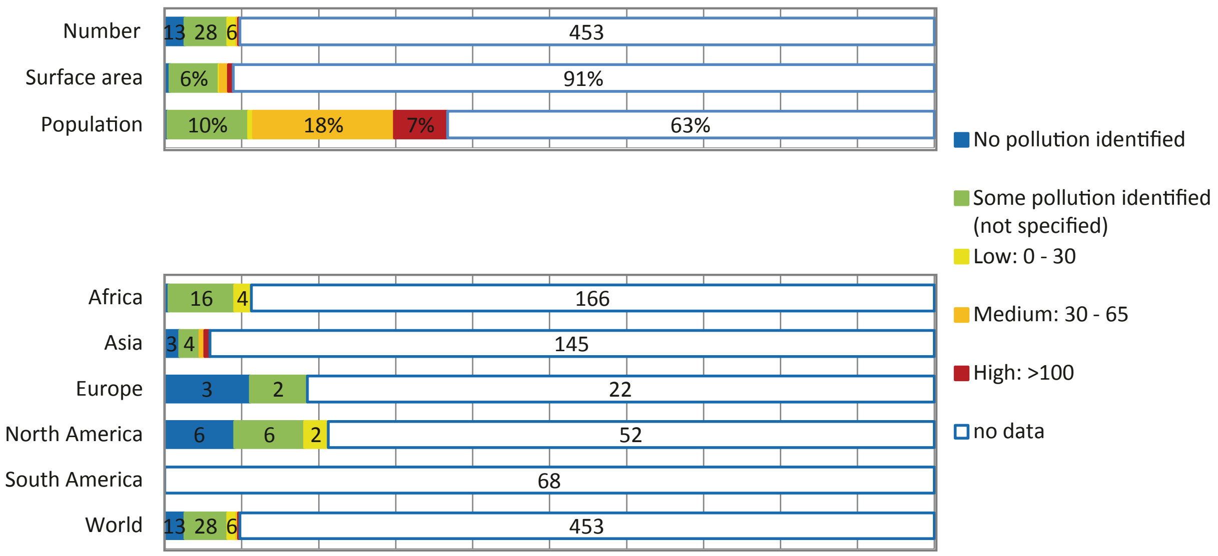
Figure 3.22. Indicator 3.1 – Groundwater depletion: distribution of TBA country segments per indicator category, based on WaterGAP.
Top diagram: distribution at global scale by no. of country segments, and percentage of surface area and population (as per cent of total TBAs area / population). Bottom: distribution per continent. Groundwater depletion is expressed in mm/year.



Groundwater pollution (Core Indicator 3.2)

The **core indicator 3.2** is defined as ‘*Observed polluted zones as a percentage of total aquifer area where water quality is below drinking standards*’. It has been computed, using Global Inventory data, for only 9 per cent of country segments of TBAs over 5 000 km^2, the majority of which lie in more densely populated areas, mainly in Asia (Figure 3.23). The indicator does not consider natural background quality.

Figure 3.23. Indicator 3.2 – Groundwater pollution: distribution of TBA country segments per indicator category, based on Global Inventory.
Top diagram: distribution at global scale by no. of country segments, and percentage of surface area and population (as per cent of total TBAs area / population). Bottom: distribution per continent. Groundwater pollution is expressed in %: percentage of total aquifer area where water quality is below drinking standards.



3.1.4. Drivers of Change and Pressures

Population density (Core Indicator 4.1)

The population density, **indicator 4.1** (Figures 3.24, 3.25, and 3.26), is defined as Number of people per unit of area on top of the aquifer. This indicator is used as part of the computation of Core Indicator 1.2 Annual amount of renewable groundwater resources per capita.

Figure 3.24. Population density 2010 (ppl/km²) per a) grid cell, b) TBA Country Segments, c) TBA.

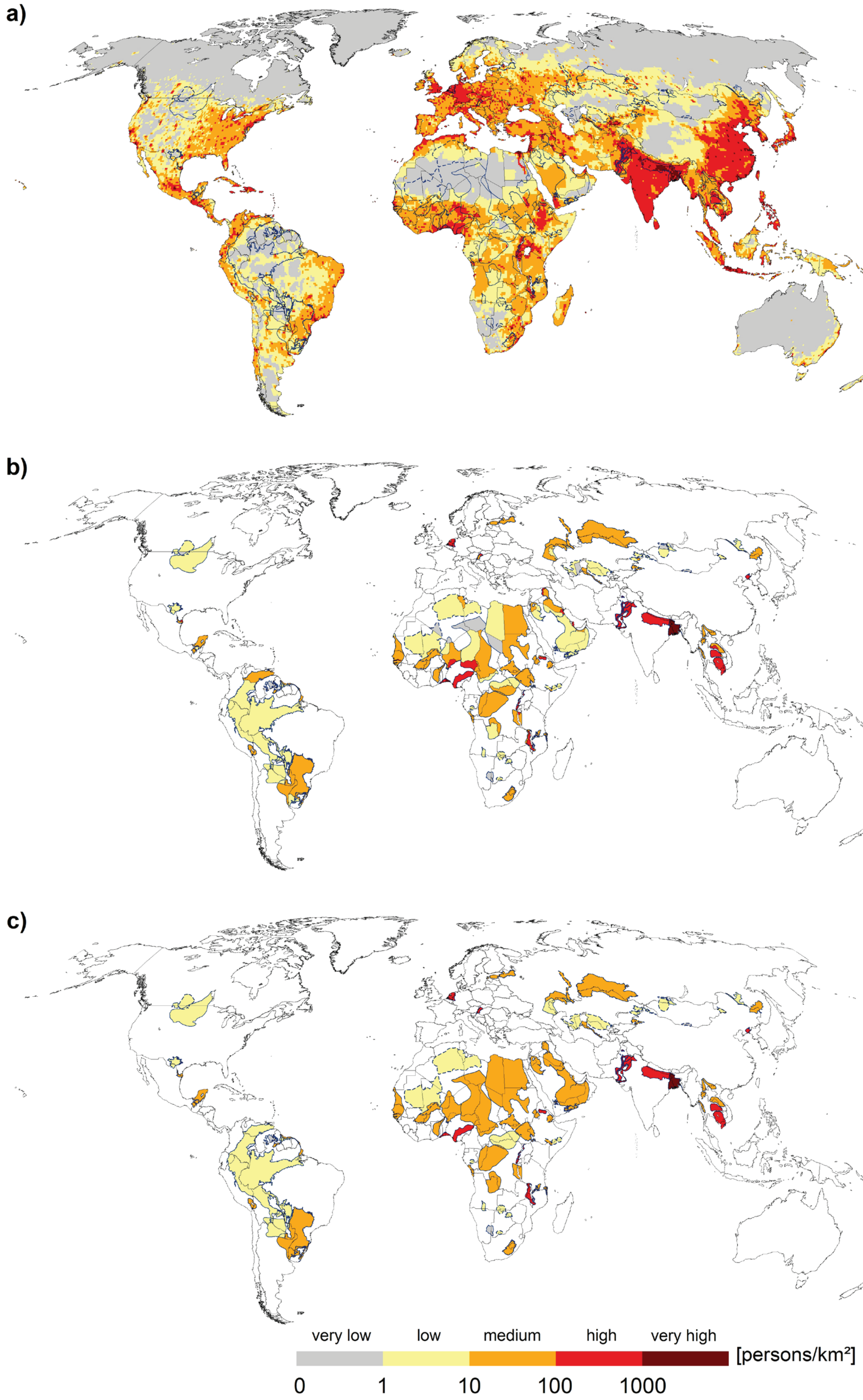


Figure 3.25 . Indicator 4.1 – Population density: distribution of Global Inventory TBA country segments per indicator category. Top diagram: distribution at global scale by no. of country segments, and percentage of surface area and population (as per cent of total TBAs area / population). Bottom: distribution per continent. Population density is expressed in capita per km².

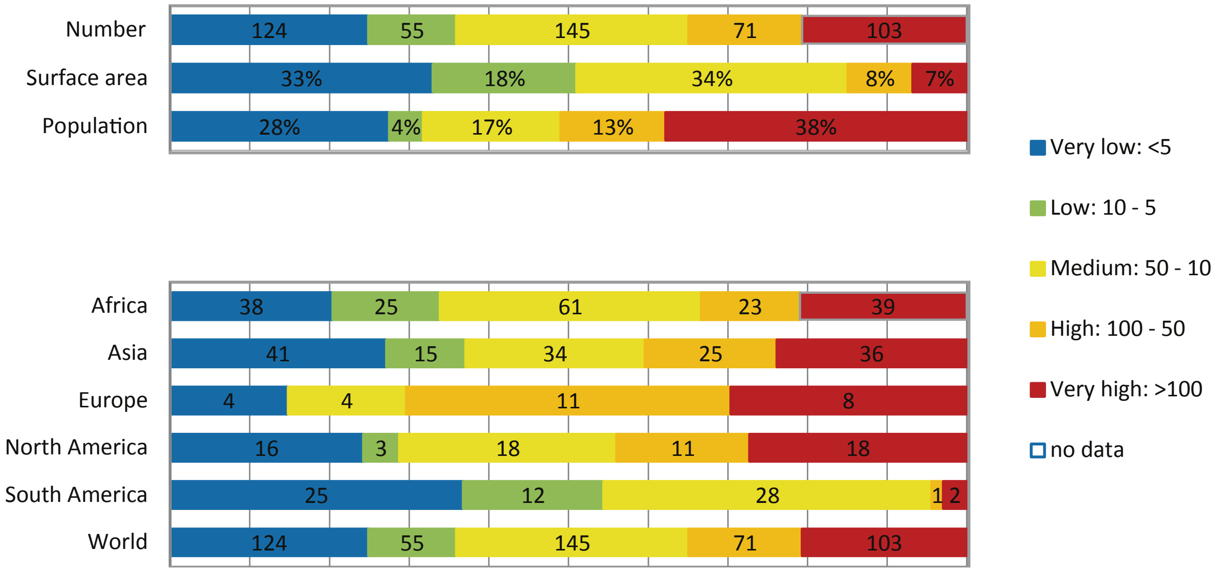
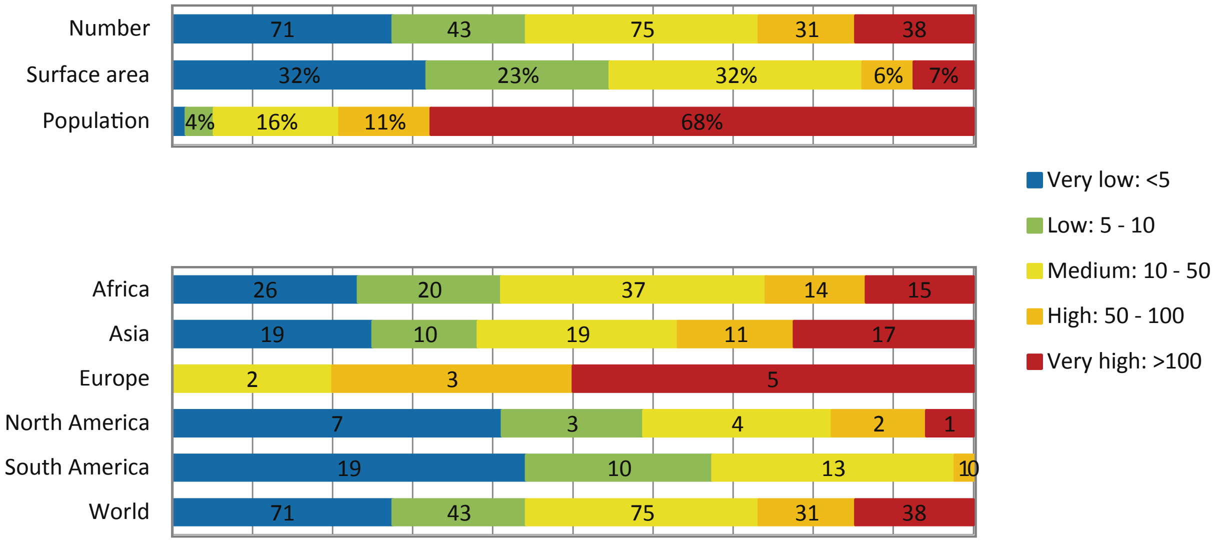


Figure 3.26 . Indicator 4.1 – Population density: distribution of WaterGAP TBA country segments per indicator category. Top diagram: distribution at global scale by no. of country segments, and percentage of surface area and population (as per cent of total TBAs area / population). Bottom: distribution per continent. Population density is expressed in capita per km².



Groundwater development stress (Core Indicators 4.2 and 4.2a)

Using WaterGAP, two versions of this indicator have been calculated for all TBAs over 20 000 km^2 (indicators 4.2 and 4.2a) (Figure 3.27, 3.28, and 3.30). Data from the Global Inventory cover 22 per cent of country segments and 7 full TBAs (Figure 3.29).

Indicator 4.2 targets the degree of modification of the groundwater budget, which has repercussions for outflow and storage. It is defined as Total annual groundwater abstraction divided by long-term mean annual groundwater recharge, and is computed as the ratio of annual groundwater abstractions to mean annual groundwater resource recharge, including artificial recharge from irrigation.

Key findings

The indicator 4.2 describes modification of renewable groundwater resources by human groundwater use. A value of 100 per cent is reached if water withdrawals equal natural plus artificial groundwater recharge. Figure 3.27 shows the major regions in the world at the grid-cell level that suffer from groundwater development stress. In general, most TBAs are located outside highly-affected regions. Country segments with groundwater withdrawals accounting for more than 50 per cent of renewable groundwater resources include aquifers in northern Africa (Lake Chad basin aquifer, Taoudeni basin aquifer), the Arabian Peninsula (Tawil Quaternary Aquifer System, Saq-Ram Aquifer System) and India (South of outer Himalayas aquifer, East Ganges River Plain aquifer). Other country segments suffering from groundwater development stress satisfy between 35 and 91 per cent of their water demand from groundwater.

Indicator 4.2a, in combination with indicator 4.2, allows for a more differentiated assessment of groundwater development stress. Indicator 4.2a is defined as the ratio of mean annual net groundwater abstractions (NAg) to mean annual natural groundwater recharge (without return flows from irrigation), hence it can measure the modification of groundwater resources even if no groundwater is abstracted at all, as a result of return flows from surface water irrigation. NAg is computed in WaterGAP as the difference between total water abstractions of groundwater and return flows to groundwater from surface water and groundwater irrigation. Thus, in regions with extensive surface water irrigation, NAg can become negative, indicating that water is being added to groundwater storage.

Key findings

Country segments identified as being under very high groundwater development stress based on indicator 4.2 remain in the same category using indicator 4.2a with even slightly higher values. In country segments with groundwater withdrawals of less than 100 per cent of groundwater recharge (indicator 4.2), indicator 4.2a generally shows a decrease of groundwater development stress, as the groundwater use component in this ratio (NAg) is reduced by return flows as compared to water withdrawals. In Figure 3.28 these decreases are very distinct in the Nubian Sandstone Aquifer System and the Indus River Plain aquifer, since these regions are characterized by extensive surface water irrigation. Regarding the Indian shares of the East Ganges River Plain aquifer and the South of outer Himalayas aquifer, where groundwater withdrawals account for 50 per cent and 80 per cent of renewable groundwater resources, groundwater development stress as measured by indicator 4.2a is reduced to 27 per cent and 64 per cent, respectively, in these country segments.

Figure 3.27. Current-state indicator 4.2 – Groundwater development stress in per cent : annual groundwater abstraction divided by mean annual groundwater recharge, including artificial recharge from irrigation per a) grid cell, b) TBA Country Segments, c) TBA.

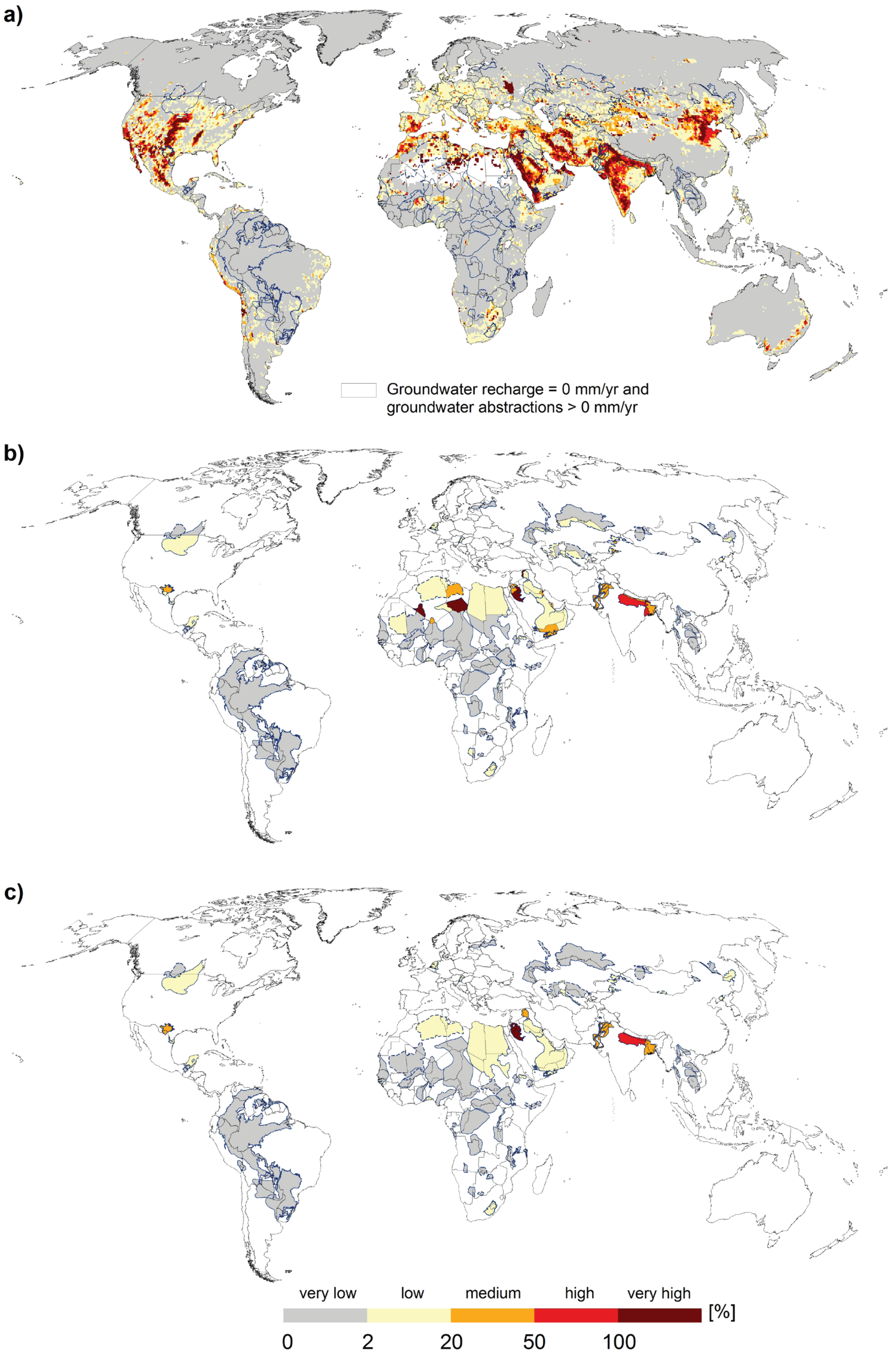


Figure 3.28. Current-state indicator 4.2a – Mean annual groundwater abstraction divided by mean annual natural groundwater recharge in per cent per a) grid cell, b) TBA Country Segments, c) TBA.

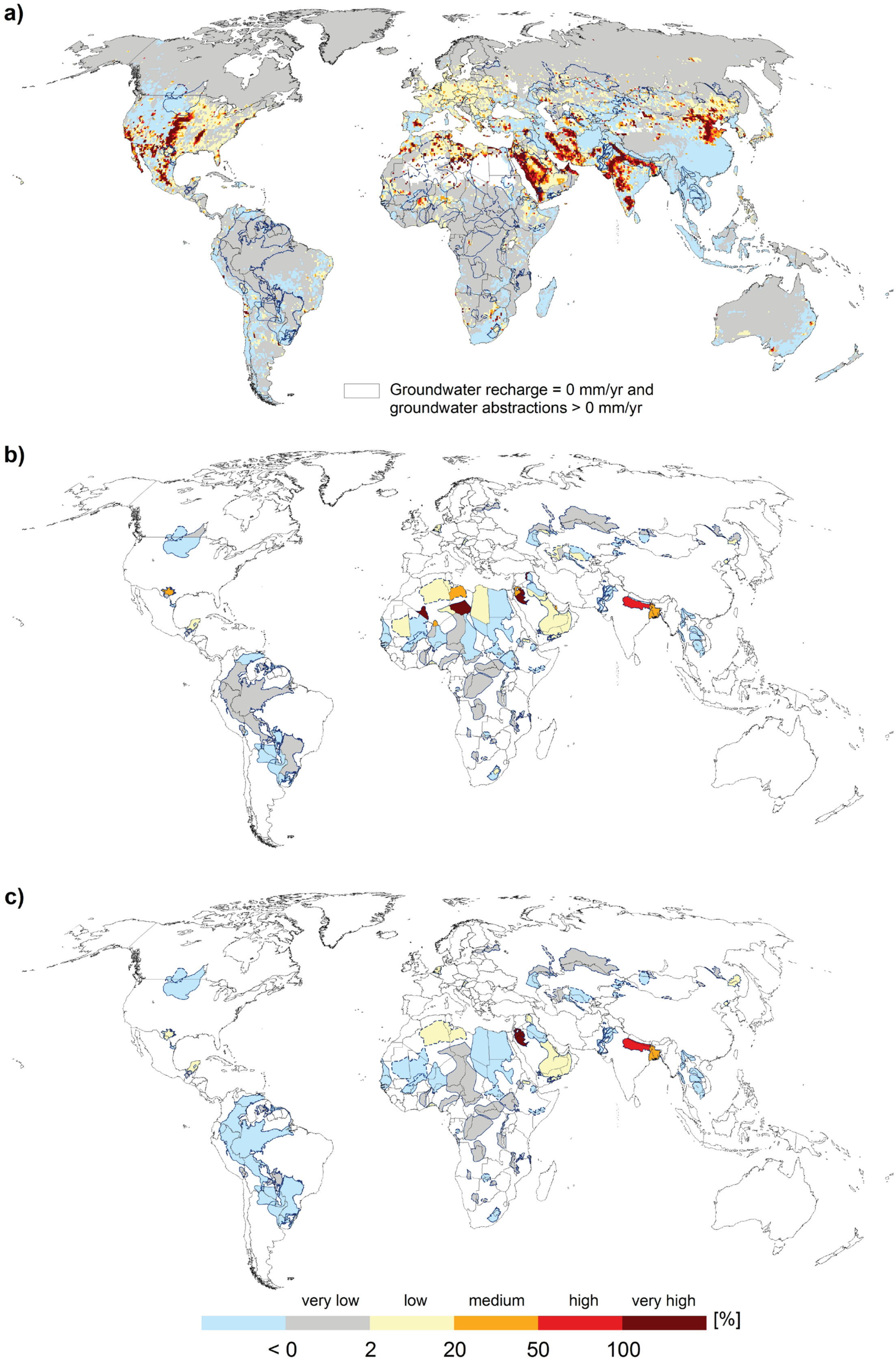


Figure 3.29 . Indicator 4.2 – Groundwater development stress: distribution of TBA country segments per indicator category, based on Global Inventory.
Top diagram: distribution at global scale by no. of country segments, and percentage of surface area and population (as per cent of total TBAs area / population). Bottom: distribution per continent. Groundwater development stress is expressed in %: percentage of annual groundwater abstraction on long-term mean annual groundwater recharge.

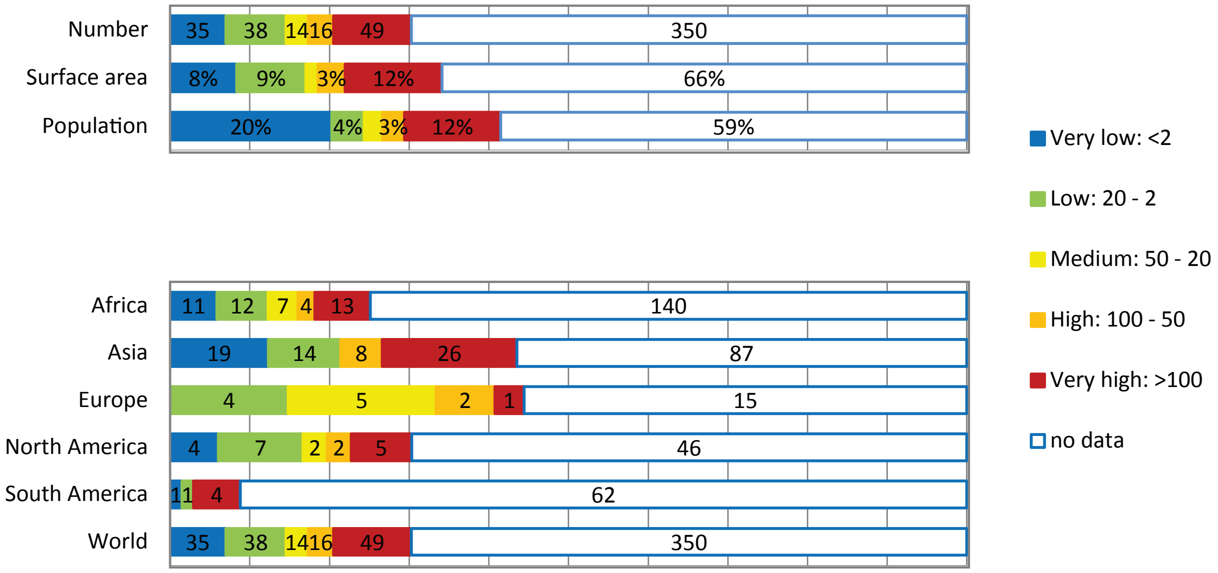
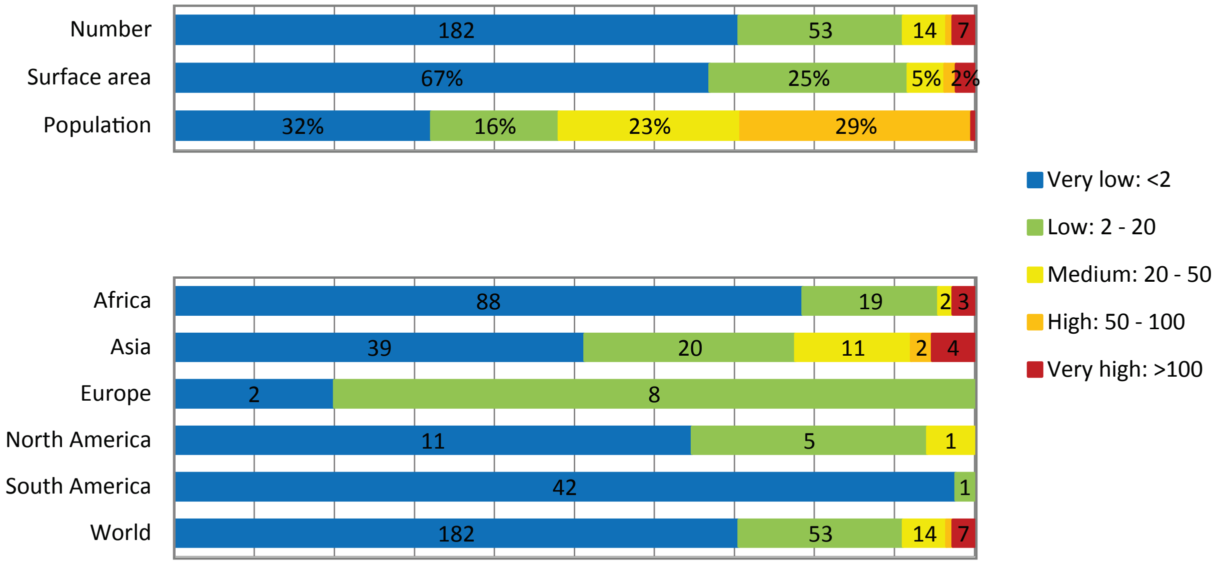


Figure 3.30 . Indicator 4.2 – Groundwater development stress: distribution of TBA country segments per indicator category, based on WaterGAP.
Top diagram: distribution at global scale by no. of country segments, and percentage of surface area and population (as per cent of total TBAs area / population). Bottom: distribution per continent. Groundwater development stress is expressed in %: percentage of annual groundwater abstraction divided by long-term mean annual groundwater recharge.



3.1.5. Enabling environment for transboundary aquifer management

Two indicators were developed to describe the enabling environment for transboundary aquifer management: Indicator 5.1 describes the transboundary legal framework and indicator 5.2 the transboundary institutional framework. The indicators aim to capture to what extent the countries sharing the transboundary aquifers are equipped to face the challenges related to the sustainable management and development of the shared groundwater resources. The indicators are closely linked to indicators 6.1 and 6.2 describing the implementation of groundwater resources management (see section 3.1.6), and together the four indicators provide an overview of the governance of the transboundary aquifers.

Transboundary legal framework (Core Indicator 5.1)

Indicator 5.1 – Transboundary Legal Framework maps the presence and scope of agreements / treaties on transboundary aquifers. The source of data is the Global Inventory, with coverage of 38 per cent of country segments, including 25 full TBAs (see Figures 3.31 and 3.32). The indicator provides a first overview of the set of legal instruments underpinning, at least on paper, TBA relationships across the globe.

From the survey it is clear that only a handful of specific agreements on transboundary aquifers exist. It is remarkable that for many transboundary aquifers the data from countries sharing an aquifer are not consistent between all countries, while this is what one would expect in the case of transboundary agreements. Also not all aquifers which are known to have agreements (e.g. the Guaraní Aquifer System, North-western Sahara Aquifer System, Nubian Sandstone Aquifer System and Illumeden Aquifer System; Eckstein & Sindico, 2014) are identified through the survey. One explanation for these seemingly inconsistent data is the fact that the Global Inventory was executed at country segment level and not all countries sharing TBAs with known agreements provided information for the Global Inventory. Another explanation lies in the fact that an agreement may not yet have been ratified in all countries involved, as is the case for example with agreement on the Guaraní Aquifer System, resulting in different answers between different countries sharing the aquifer.

It is also possible that experts from different countries may interpret the agreement differently. This is likely to be the case for those TBAs which don’t have agreements specifically dedicated to transboundary groundwater but have agreements on transboundary waters in general: across the world many agreements exist on the management of international river basins, and there may be differences of interpretation between national experts contributing to the Global Inventory to what extent these agreements also cover transboundary aquifers.

Figure 3.31. Indicator 5.1 – Transboundary legal framework by TBA country segments .

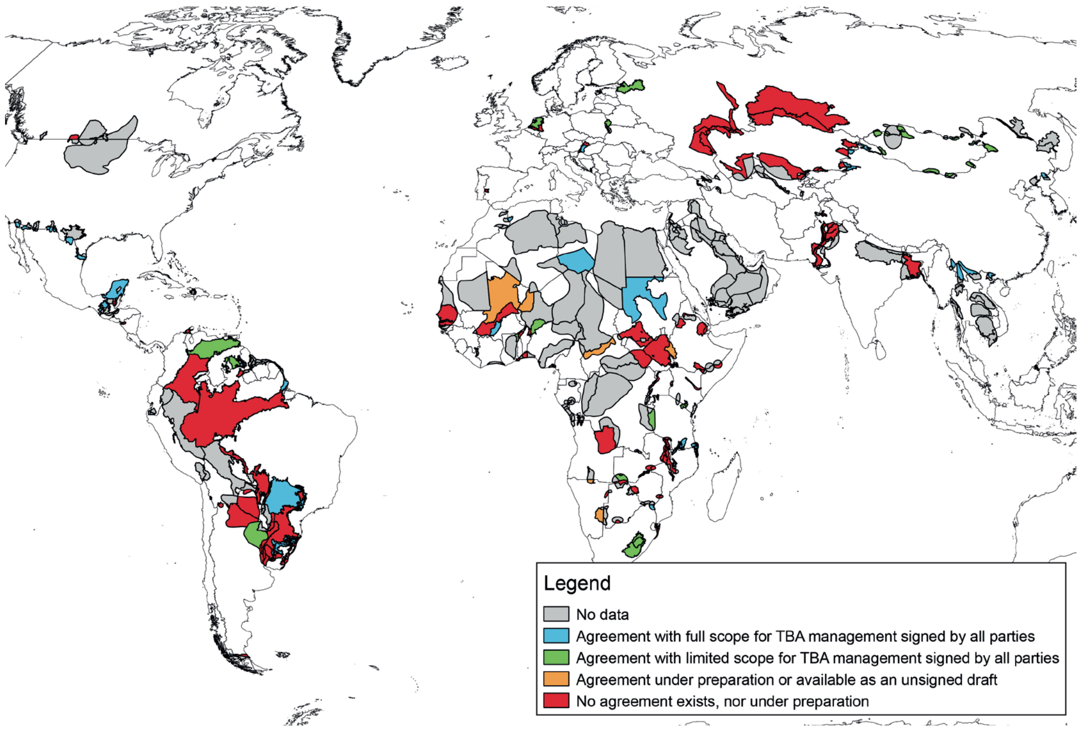
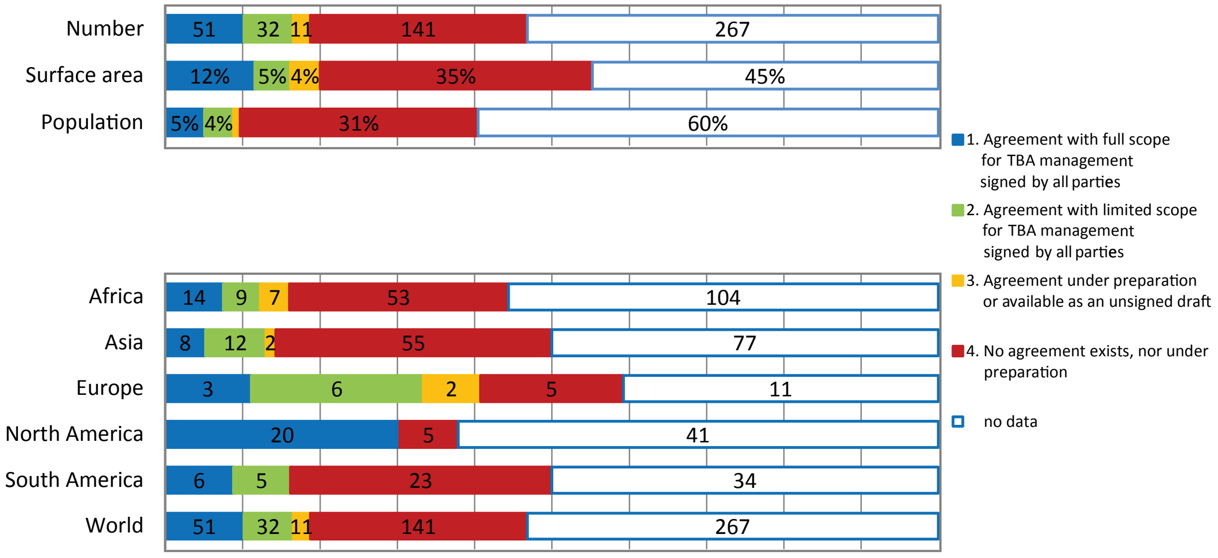


Figure 3.32 . Indicator 5.1 – Transboundary legal framework: distribution of TBA country segments per indicator category, based on Global Inventory (per continent and at global scale).



Transboundary institutional framework (Core indicator 5.2)

Next, the institutional framework indicator relates to the existence, mandate and capabilities of institutions or institutional arrangements for managing the transboundary aquifer under consideration (all types of intervention). Like indicator 5.1, its data source is the Global Inventory with a similar coverage. This indicator maps the presence of institutions for managing TBAs, and gauges the scope of their remit, and their capacity to deliver.

The governance indicators are based on the premise that the governance of a TBA is guided by (among other things) the legal agreements and the organizations in place, and that these provide a framework for managing the shared water resources of an aquifer. These agreements and organizations, while reflecting the prevailing principles of international water law governing TBAs in general, go further as they operationalize such principles in the specific context of each TBA. As a result, each TBA-specific agreement and the relevant transboundary organization are an indicator of cooperative TBA management. This assessment maps the presence of TBA agreements and TBA organizations to determine the extent to which dealings among TBA States are set on a cooperative course, and supported by binding rules and a transboundary organization.

Figure 3.33. Indicator 5.2 – Transboundary institutional framework by TBA country segments.

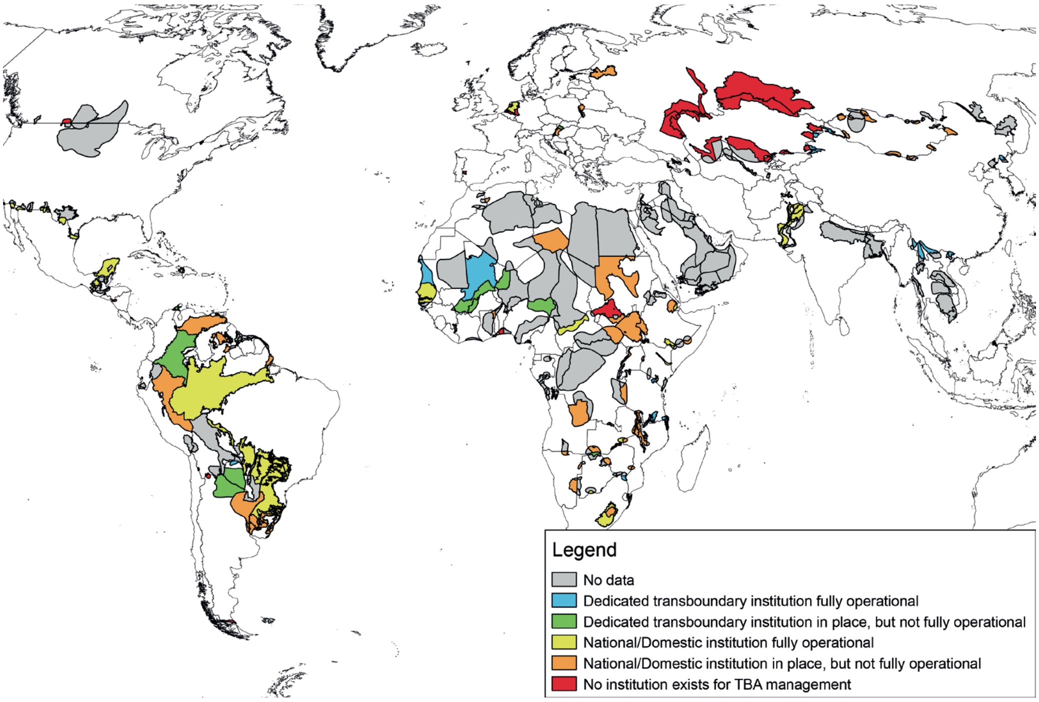
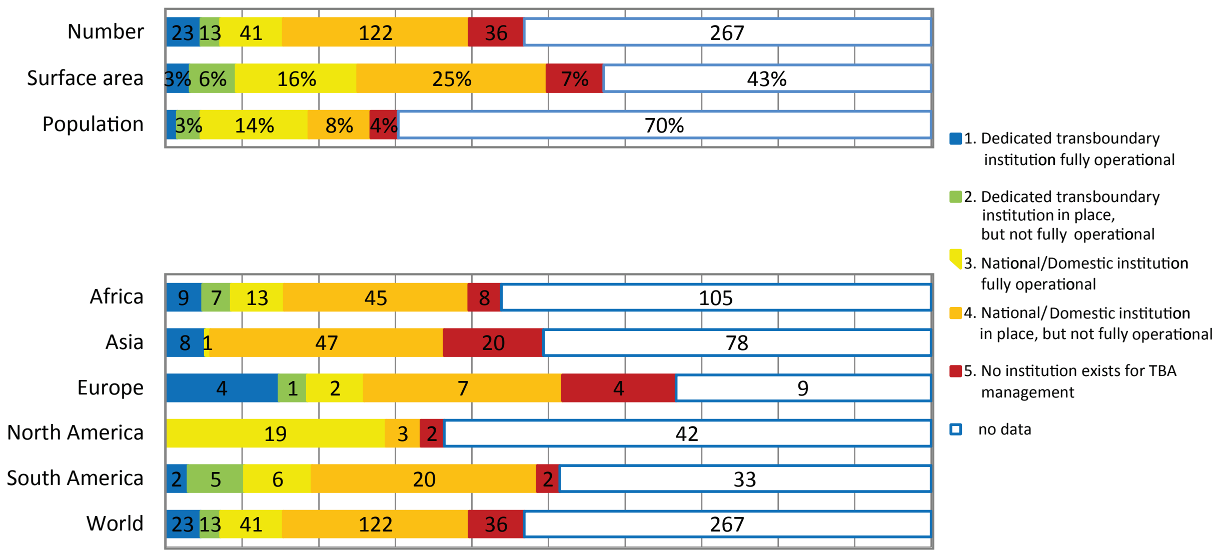


Figure 3.34 . Indicator 5.2 – Transboundary institutional framework: distribution of TBA country segments per indicator category, based on Global Inventory (per continent and at global scale).



Key findings

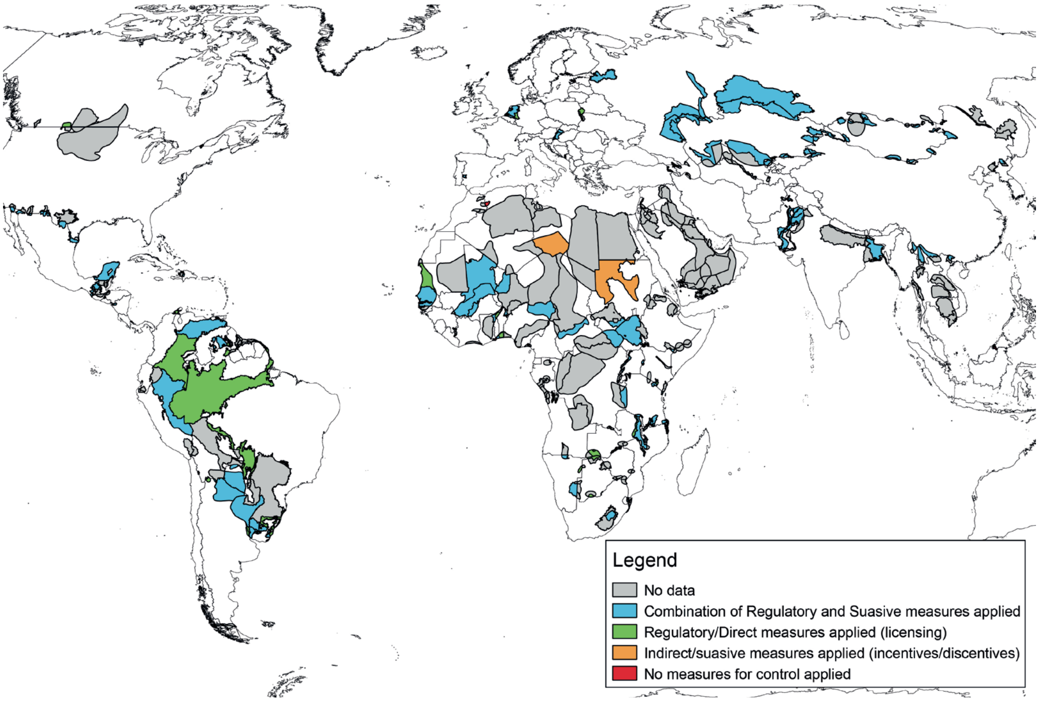
- Only a handful TBA-specific agreements exist: worldwide there are 6 transboundary aquifers with specific agreements and 2 aquifers with informal agreements. To some extent the management of transboundary aquifers – if only by implication - may be dealt with in the framework of agreements on international river basins under the mandate of international river basin organisations.
- The scope of the treaties and agreements on record varies widely, ranging from an articulate web of procedural and substantive obligations (Genevese TBA, Europe) to a framework setting out the basic parameters for further agreement (an 'agreement to agree' at some later stage) (Guaraní TBA, South America).
- TBA-specific transboundary institutions complement the TBA agreements on record.
- The vast majority of TBAs have no agreement in place. Nonetheless, the relevant aquifer countries are bound by a few principles of customary international water law: (a) the principle of equitable and reasonable utilization; (b) the principle of not causing significant harm; (c) the principle of cooperation and information exchange; (d) the principle of prior notification, consultation or negotiation; (e) the principle of peaceful settlement of disputes. Moreover, endorsement of/support for the (non-binding) UN Resolution 63/128 (2008) on the Law of Transboundary Aquifers by a TBA country or countries can provide a useful indication of allegiance of the country or countries to the elaborate set of rules articulated therein for the management, protection and conservation of TBAs, in addition to the core customary law principles listed above. However, the principles of customary international water law, and the UN Resolution 63/128, are no substitute for a legally-binding TBA agreement and organization that set out the obligation to cooperate and the relevant terms of engagement among the concerned States.
- While development of the domestic legal and institutional environment for sustainable water resources management is advancing in a majority of TBAs, the patchy evidence on record only allows for highest-order generalizations.

3.1.6. Changes in Groundwater Status

Control of groundwater abstraction (Additional indicator 6.1)

This indicator describes the current practices on the implementation of measures to control groundwater abstraction, differentiated in four categories with decreasing levels of control. The data source is the Global Inventory, with coverage of 33 per cent of country segments, including 20 full TBAs, all of which except one (Nubian Aquifer in Sudan), report some level of regulatory regime.

Figure 3.35. Current-state indicator 6.1 – Control of groundwater abstraction by TBA country segments.



Groundwater quality protection (Additional indicator 6.2)

This complementary indicator maps the current practices on the implementation of groundwater quality protection, with similar categories to indicator 6.1. The coverage is 31 per cent of country segments, including 17 full TBAs. With the exception of three smaller TBAs in Southern Africa, all report the existence of some level of regulatory measures.

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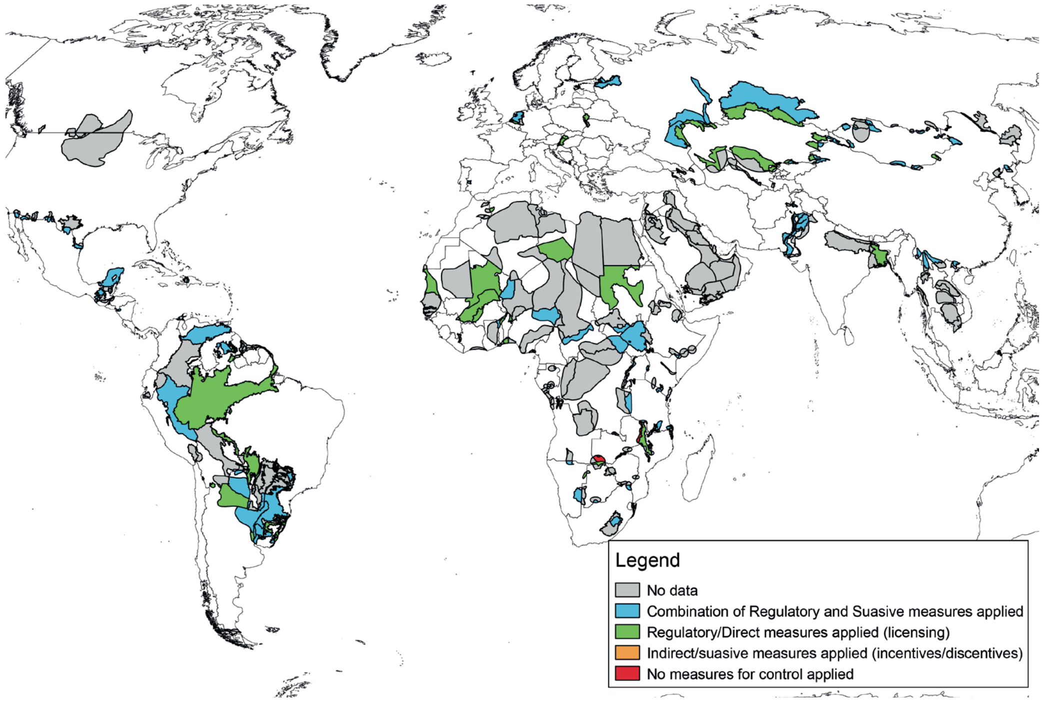
Figure 3.36. Current-state indicator 6.2 – Groundwater quality protection by TBA country segments.



3.2. Projected indicators

Different groundwater indicators (1.2, 2.1, 4.1, 4.2, and 4.2a), for current (2010) conditions and conditions projected for 2030 (simulation period 2021-2050) and 2050 (simulation period 2041-2070), were quantified using WaterGAP 2.2 to contribute to a global baseline assessment of major TBAs for 91 selected TBAs larger than 20 000 km² (Table 2.3). Current-state indicators were computed using the Watch Forcing Data climate dataset, while projections are based on five climate scenarios computed by five global climate models (GCMs)[22] for the high-emissions scenario RCP8.5 . Current conditions are presented as absolute values; projections show percentage changes from current conditions, as ensemble means of the results of individual GCMs, but separately for each irrigation scenario. Water-use projections are based on the Shared Socio-economic Pathway SSP2 developed within ISI-MIP. For individual water-use sectors, the fraction of groundwater abstraction was assumed to remain at the current level. Two further irrigation scenarios were also considered, with either temporally constant or variable irrigation areas. This results in a total of ten scenarios for each of the simulation periods 2021-2050 and 2041-2070.

For indicators already quantified in percentage terms (indicators 2.1, 4.2, and 4.2a), future changes are expressed as changes in percentage points, while future changes of indicators 1.2 (in m³ per capita per year) and 4.1 (in persons/km²) are presented as percentage changes. The GCM-specific percentage changes or changes in percentage points were arithmetically averaged, resulting in ensemble mean values for each projected indicator (per time period and irrigation scenario). Ensemble means are considered as robust indicators, balancing the errors of individual models, and the conciseness of ensemble means facilitates the interpretation of model results, especially by non-experts. However, as the risks of climate change may be underestimated because of the averaging over model results, projected hotspots of groundwater stress were identified using the 'worst-case scenario' among the five individual GCMs.

To gain an impression of the variability of groundwater resources and withdrawals as computed using different climate inputs (5 GCMs and the observed Watch Forcing Data (WFD)), global totals of mean annual groundwater

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[22] Climate scenarios developed in the framework of the ISI-MIP project.

Table 3.1. Comparison of modelled global nature groundwater recharge and water withdrawal from groundwater under current conditions for each GCM and irrigation as well as Watch Forcing Data (WFD) and projected percentage changes compared with current-conditions

Climate data	GMIA5* 2005		AAI**constant		AAI LandSHIFT	
	1971-2000 [km^3/yr]	2010 [km^3/yr]	2041-2070	2050	2041-2070	2050
	$R_{g,nat}$	WW_{gw_irr}	$R_{g,nat}$	WW_{gw_irr}	$R_{g,nat}$	WW_{gw_irr}
GFDL-ESM2M	16 750	608	-2.8%	10.9%	-2.8%	15.1%
HadGEM2-ES	17 384	634	-1.5%	8.4%	-1.5%	11.6%
IPSL-CM5A-LR	17 166	614	-0.03%	8.8%	0.01%	12.3%
MIROC-ESM-CHEM	17 364	572	0.8%	11.6%	0.9%	13.3%
NorESM1-M	17 148	579	-1.0%	8.4%	-0.9%	10.9%
WFD	15 926	609	-	-	-	-

(Groundwater recharge includes contributions from surface water bodies but no return flows from irrigation)
** Version 5 of the Global Map of Irrigated Areas*
** * Areas actually irrigated*

recharge and annual withdrawals from groundwater were compiled in Table 3.2 for the reference years 2010 and 2050 for all model runs. Modelled groundwater recharge for 1971-2000 is lowest on the basis of WFD, while water withdrawals on the basis of GCMs range between 94 per cent and 104 per cent of the WFD result. Projected trends of natural groundwater recharge between the two irrigation scenarios are similar, while increases in water withdrawals are more pronounced in the ‘AAI LandSHIFT’ scenario. The largest increases and decreases, respectively, result from model runs forced with GFDL-ESM2M climate data.

3.2.1. Indicator 1.2 and 4.1 – Groundwater recharge per capita

Projections of mean annual groundwater recharge per capita (1.2) are presented as ensemble means of percentage changes in 2030 and 2050 from current conditions. Figure 3.37 shows the results for the irrigation scenario ‘AAI constant’ in 2030 (centre) and 2050 (bottom) as well as current conditions at the country segments level (top). Results for the irrigation scenario ‘AAI LandSHIFT'[23] are shown in Figure 3.37 Projected percentage changes of population density (4.1) in 2030 and 2050 are shown in Figure 3.38.

Changes in per-capita groundwater resources are influenced by climate, increased or decreased return flows from irrigation due to changed irrigated areas (only for scenario ‘AAI LandSHIFT’), and projected population density in 2030 and 2050.

For constant irrigated areas in 2030, per-capita groundwater resources in 211 out of 258 country segments (82 per cent) are reduced compared with 2010. In 86 of these country segments, reductions between 30 and 50 per cent were computed. In 2050, negative percentage changes were computed for 221 out of 258 country segments (86 per cent). Here, 143 country segments show reductions between 30 and 100 per cent. Similar results were computed for the ‘AAI LandSHIFT’ scenario. Reductions of indicator 1.2 were identified in 208 country segments (85 TBA-CUs between -30 and -49 per cent) in 2030 and in 220 country segments in 2050 (143 country segments between -30 and -100 per cent).

A comparison between projected population changes (indicator 4.1, Figure 3.39 and percentage changes in per-capita groundwater resources indicates that population growth is an important influencing factor aggravating the groundwater situation in many African aquifers. Here, population density increases by more than 100 per cent in the Sahel region and in Central Africa. Identified hotspots of groundwater stress based on indicator 1.2 are presented in section 3.3.2.2.

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[23] In case of scenario “AAI LandSHIFT”, output of the land-use model LandSHIFT was used to scale the irrigated areas for each country.

Figure 3.37. Projected indicator 1.2 – TBA Country Segments-based ensemble mean of percentage changes from current conditions for irrigation scenario ‚AAL constant' TBA.

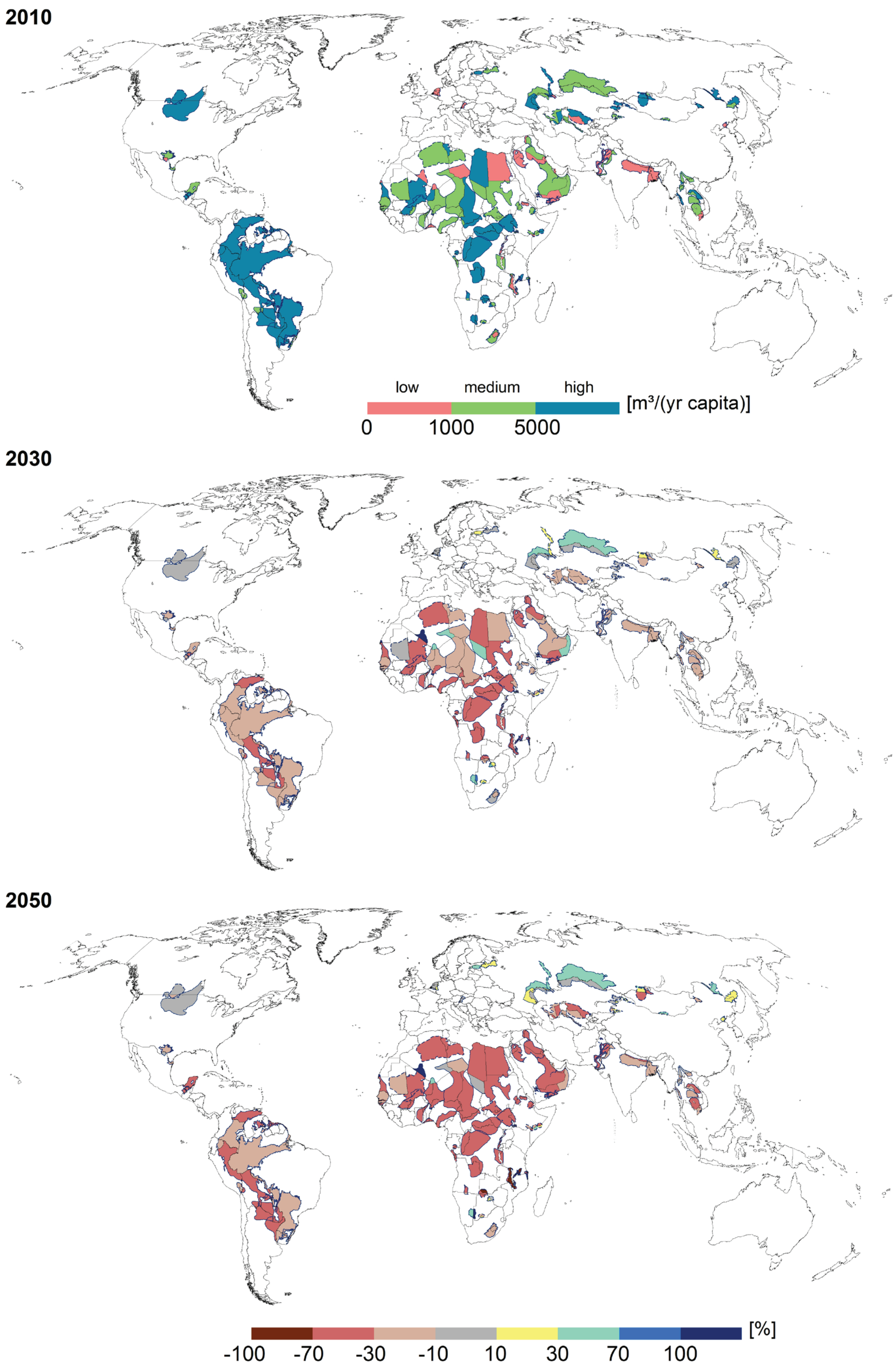


Figure 3.38. Projected indicator 1.2 – TBA Country segments-based ensemble mean of percentage changes from current conditions for irrigation scenario, AAL LandSHIFT‘.

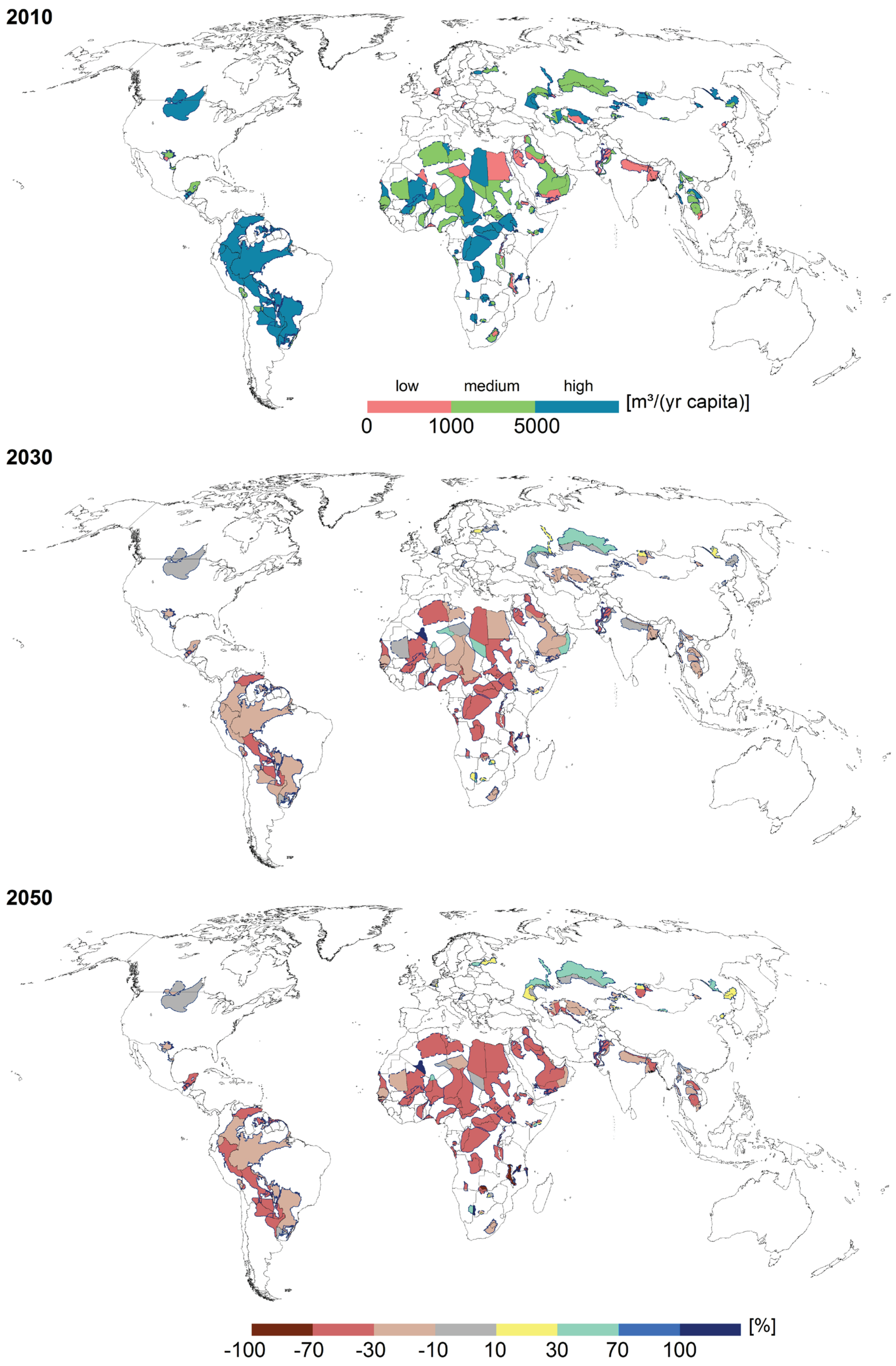
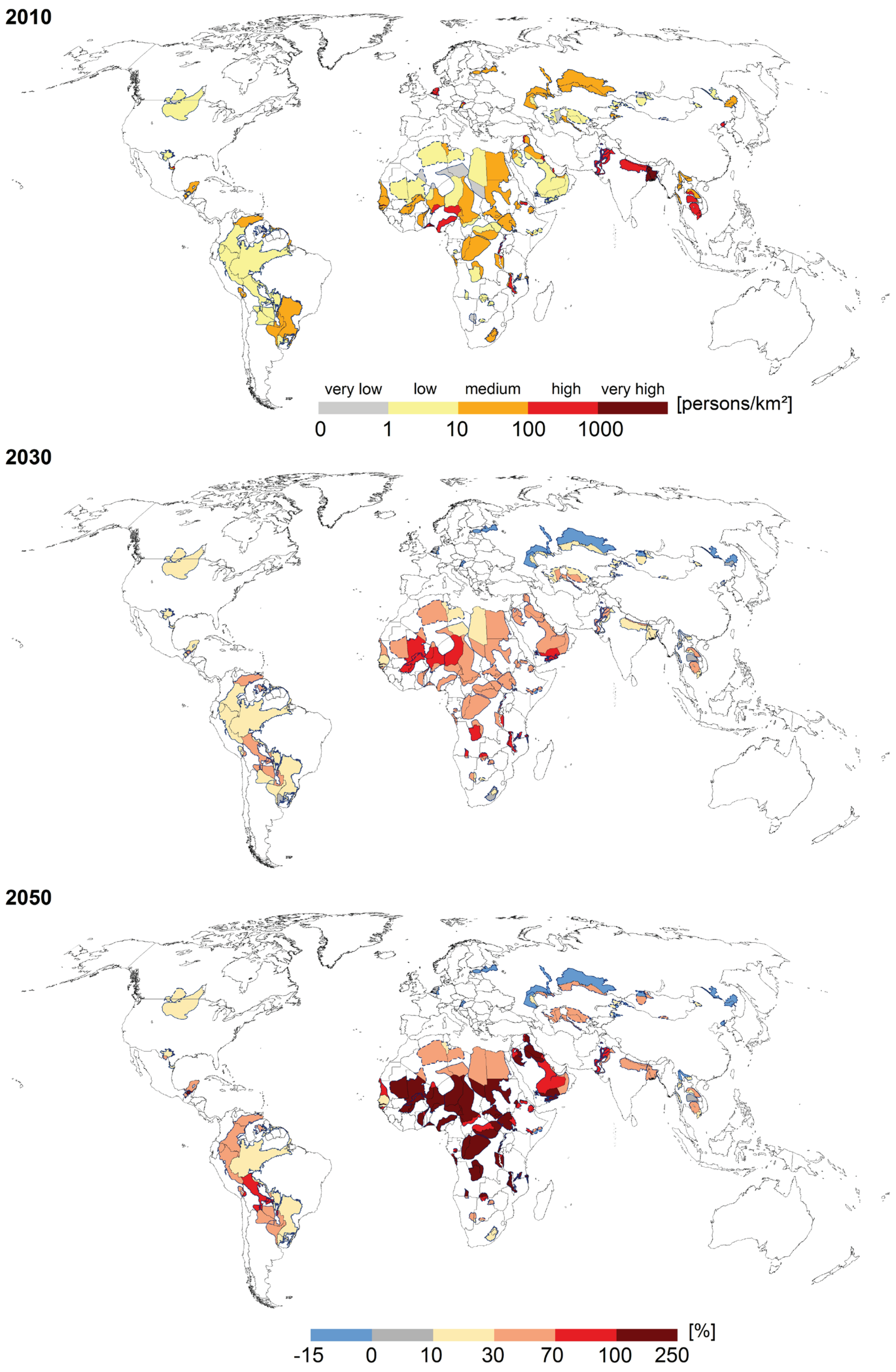


Figure 3.39. Projected indicator 4.1 – TBA Country segments-based ensemble mean of percentage changes form current conditions.



3.2.2. Indicator 2.1 – Human dependence on groundwater

In WaterGAP, groundwater uses in the different sectors are computed by multiplying total water withdrawals and consumptive use in each grid cell by sector, by cell-specific temporally constant groundwater use fractions, which are assumed to be the same for water withdrawals and consumptive use. For the purposes of this assessment, the sector-specific fractions of groundwater and surface water demand (both consumptive uses and withdrawals) are assumed constant over time. Thus, future percentage changes of indicator 2.1 are only attributable to projected changes in sectoral shares of total water demand. As an example: the assumed fractions of groundwater withdrawals in the domestic sector and the irrigation sector in a certain country are 0.7 and 0.4. Other sectors are neglected. An increase in indicator 2.1 would then indicate that the ratio of domestic water withdrawals to irrigation water withdrawals has increased.

Projections of indicator 2.1 as ensemble mean of percentage point changes are shown in Figures 3.40 ('AAI constant') and 3.41 ('AAI LandSHIFT'). In many TBAs in Africa, the Arabian Peninsula, India, and Bangladesh, dependence on groundwater decreases; increases are seen in TBAs extending over Chad, Niger, Nigeria, East Africa, and Uzbekistan. Similar to the assessment of current-state indicators, the projected indicator 2.1 is used in section 3.2.5 to present identified country segments under groundwater development stress with either a high or a low level of dependence on groundwater.

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Figure 3.40. Projected indicator 2.1 – TBA Country segments-based ensemble mean of percentage point changes from current conditions for irrigation scenario ‚AAL constant‘.

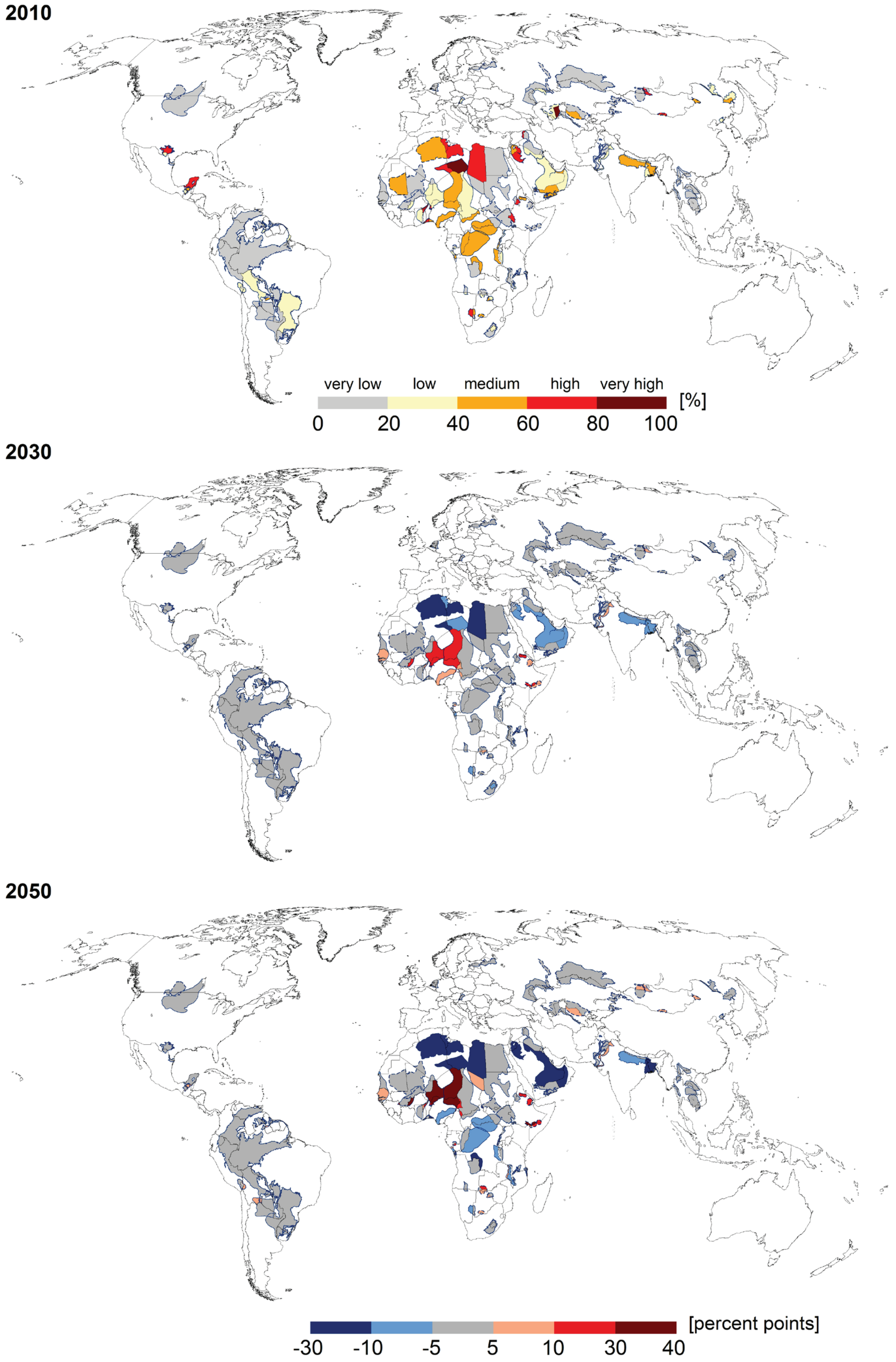
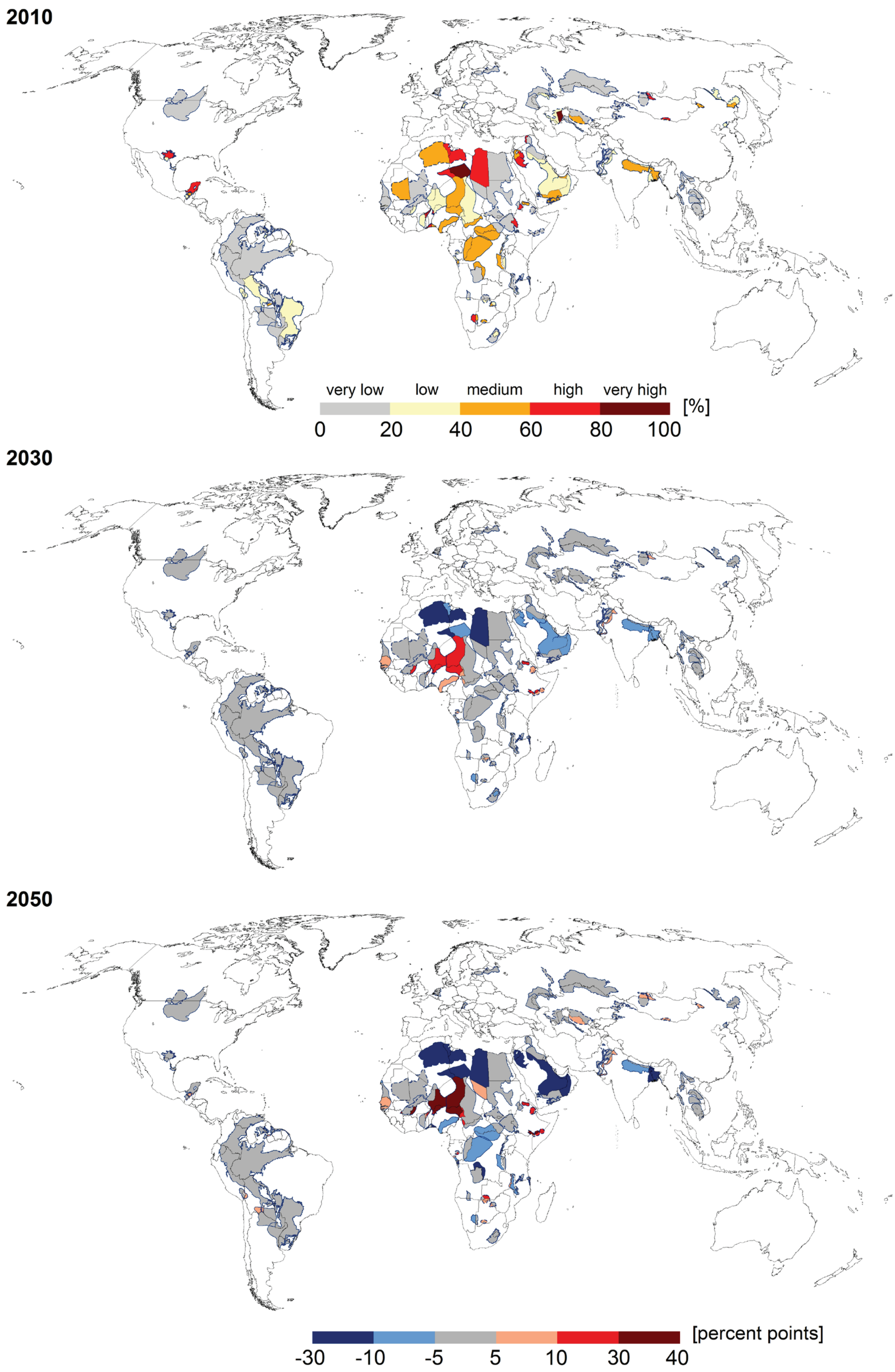


Figure 3.41. Projected indicator 2.1 – TBA Country segment-based ensemble mean of percentage point changes from current conditions for irrigation scenario ‚AAL LandSHIFT‘.



3.2.3. Indicator 4.2 – Groundwater development stress, including artificial recharge

Ensemble means of percentage point changes for indicator 4.2 are shown in Figure 3.42 ('AAI constant') and Figure 3.43 ('AAI LandSHIFT'). Modelled increases in groundwater development stress can be caused by reduced natural groundwater recharge, rising total water demand, or reduced return flows from irrigation, either because of assumed reductions in water demand for irrigation (both irrigation scenarios) or reduced irrigated areas in scenario 'AAI LandSHIFT'. A detailed evaluation of projected changes of indicator 4.2 at the TBA Country Segment level is included in the discussion in Section 3.3.2.

3.2.4. Indicator 4.2a – Groundwater Development Stress, excluding artificial recharge

Figures 3.44 and 3.45 depict ensemble means of percentage point changes for indicator 4.2a for the irrigation scenarios 'AAI constant' and 'AAI LandSHIFT'. A detailed evaluation of projected changes of indicator 4.2a at the TBA country segment level is included in the discussion in section 3.3.2.

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Figure 3.42. Projected indicator 4.2 – TBA Country segment-based ensemble mean of percentage point changes from current conditions for irrigation scenario ‚AAL constant‘.

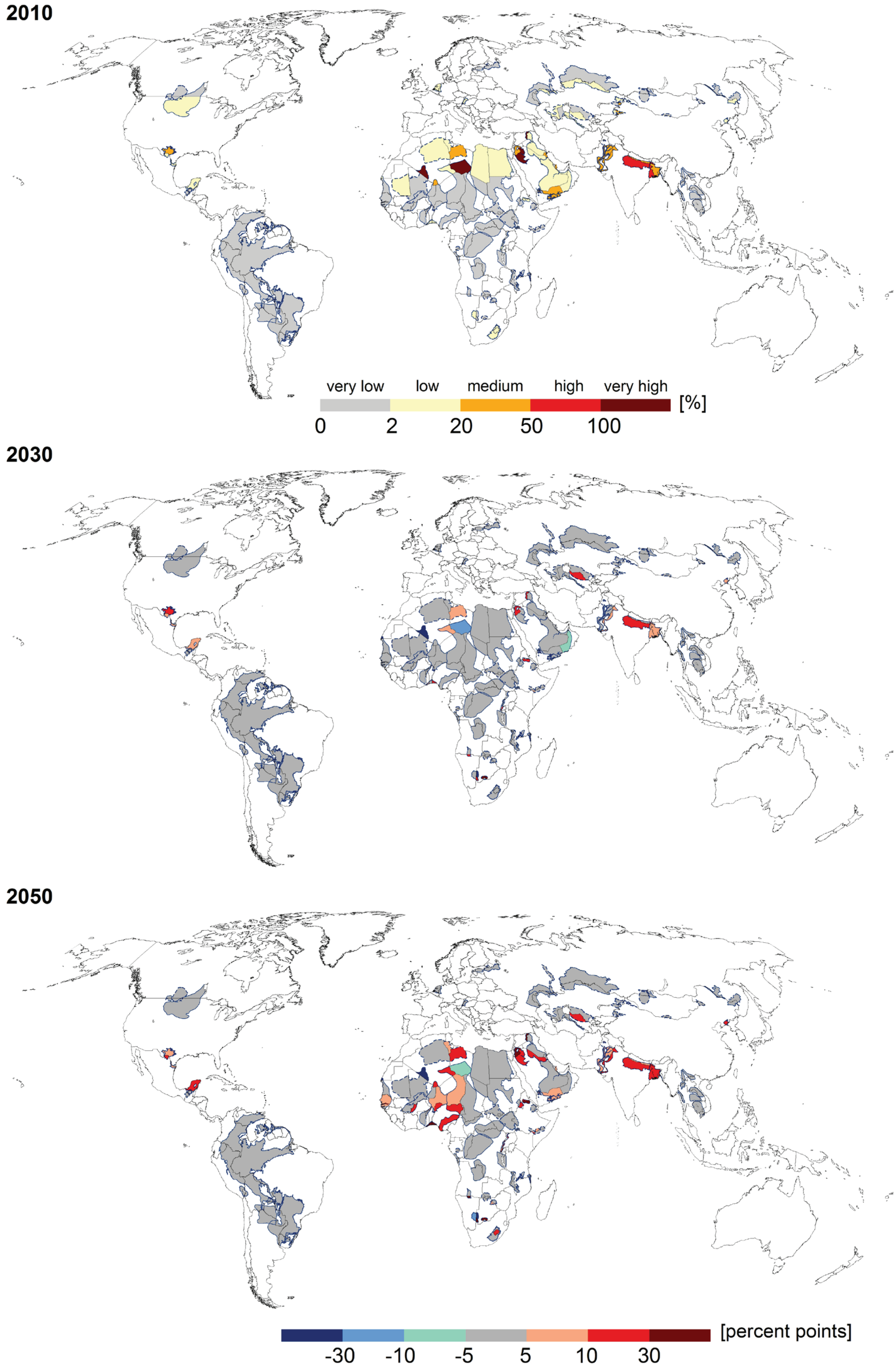


Figure 3.43. Projected indicator 4.2 – TBA Country segment-based ensemble mean of percentage point changes from current conditions for irrigation scenario ‚AAL LandSHIFT'

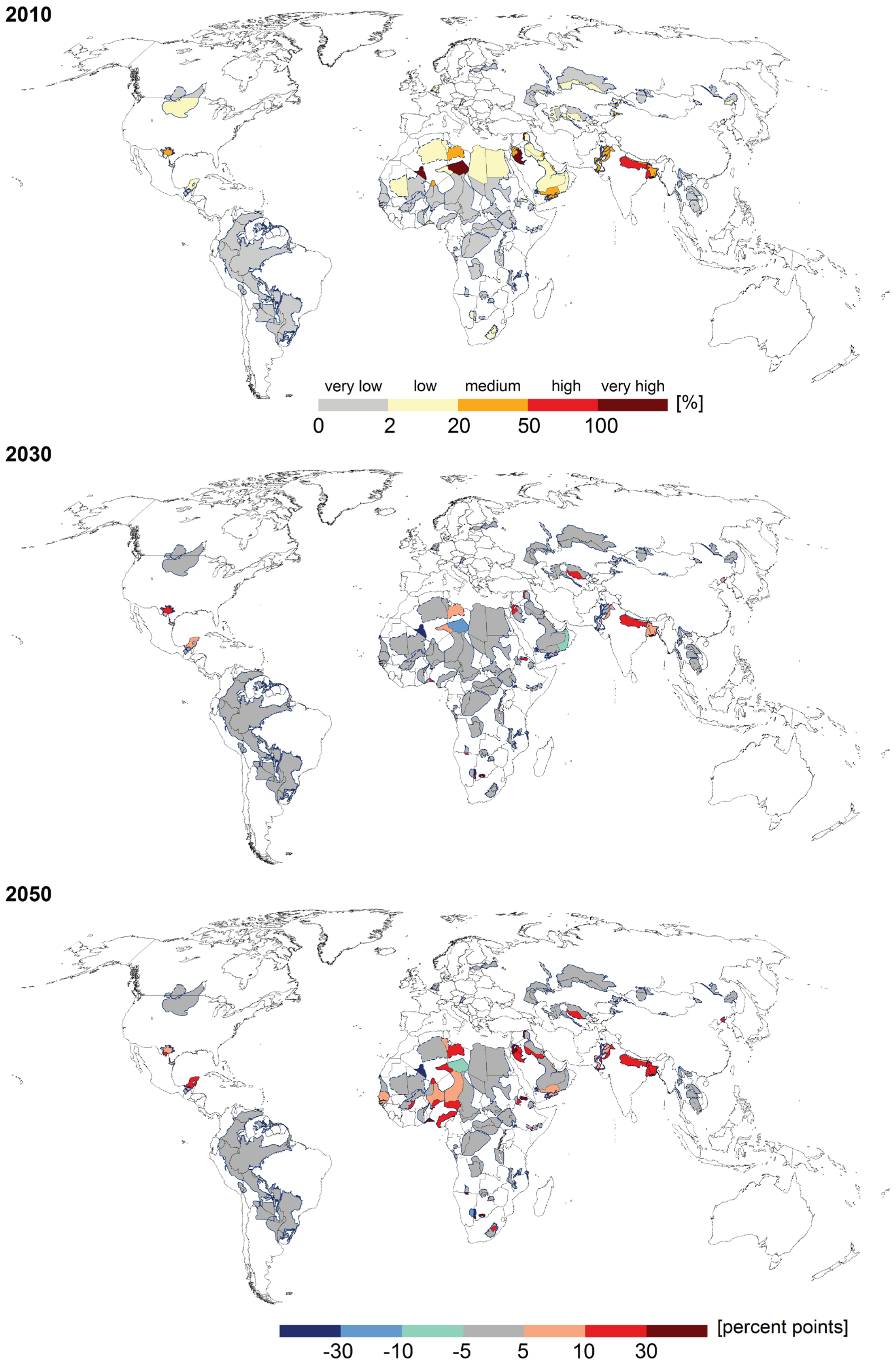


Figure 3.44. Projected indicator 4.2a – TBA Country segment-based ensemble mean of percentage point changes from current conditions for irrigation scenario ‚AAL constant‘

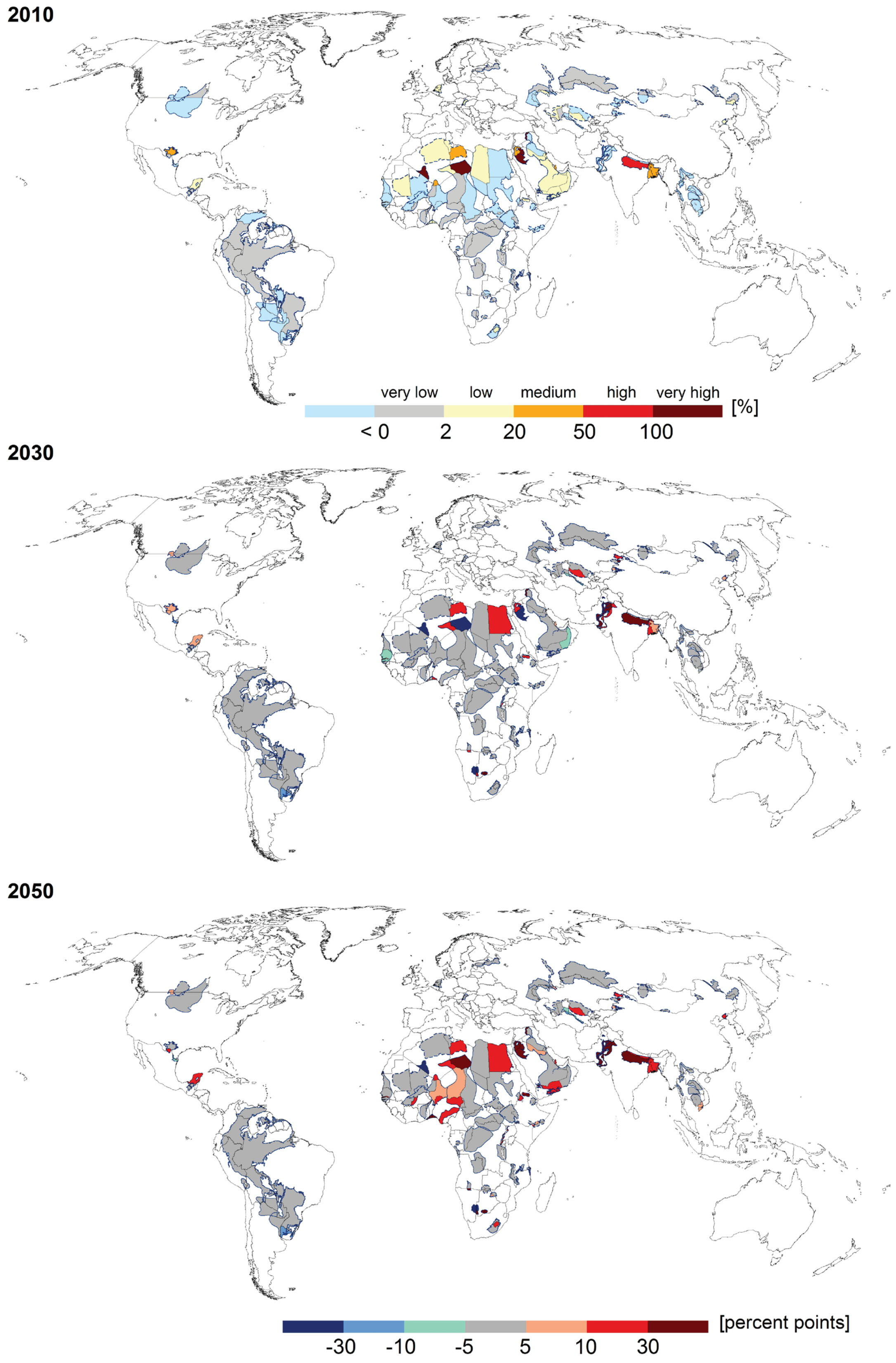
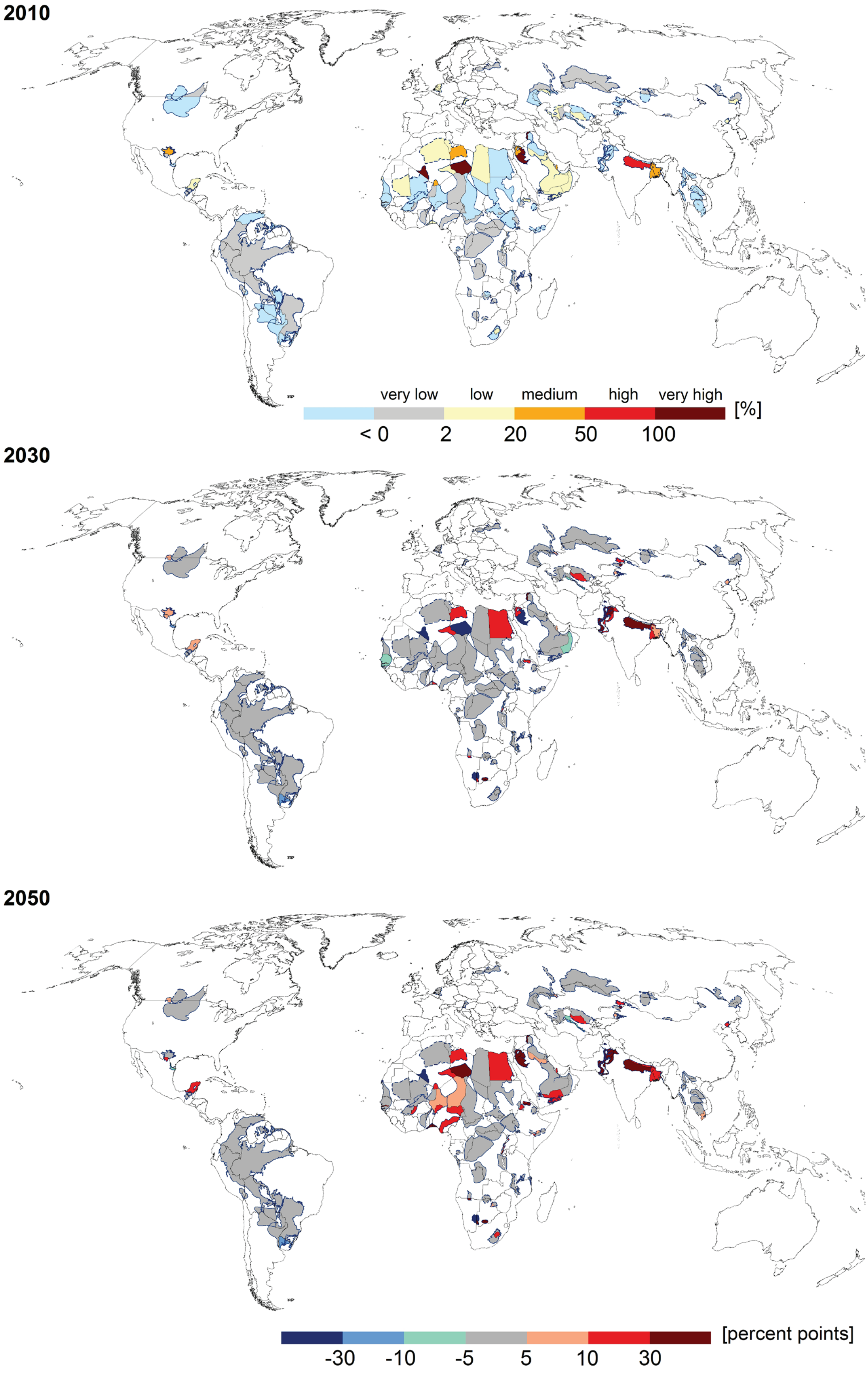


Figure 3.45. Projected indicator 4.2a – TBA Country segment-based ensemble mean of percentage point changes from current conditions for irrigation scenario ‚AAL LandSHIFT'.



3.3. Summary of key findings

3.3.1. Discussion on the Current State Indicators

Groundwater recharge

TBAs with the highest groundwater recharge rates (more than 300 mm/yr) are found in humid areas in the Amazon region, in Central Africa, and in South Asia (Amazonas aquifer, the Cuvette aquifer in Central Africa, the Indus River Plain aquifer, the East Ganges River Plain aquifer and the Khorat Plateau aquifer extending over Laos and Thailand).

TBAs with low recharge rates (2 - 20 mm/yr) are found in Northwest Africa and the Arabian Peninsula (Northwest Sahara Aquifer System and the two merged aquifers AS126_129 and AS131 located on the Arabian Peninsula). Recharges of less than 2 mm/yr were found in country segments in arid regions receiving very low groundwater recharge, namely the Nubian Sandstone Aquifer System in Chad, the northern fractions of the lake Chad Basin aquifer, the Taoudeni Basin aquifer and the Irhazer-Illuemeden Basin aquifers in Algeria, and the Uzbek part of the Syr Darya aquifer.

Return flows from irrigation over the Indus River Plain aquifer in Pakistan and India account for about 70 per cent and 40 per cent of total groundwater recharge (including induced recharge). Over the Nubian Sandstone Aquifer System, return flows from irrigation were computed at 44 per cent (Egypt) and 38 per cent (Sudan) of total groundwater recharge. Over the East Ganges River Plain aquifer, 27 per cent of total groundwater recharge is contributed by return flows.

Considering projections of groundwater recharge, per-capita groundwater recharge will decrease from 2010 to 2030 in 211 country segments (taking into account both irrigation scenarios). From 2010 to 2050, 220 will be affected by a decrease. In all cases, more country segments are negatively affected for the scenario with constant irrigated areas.

Low recharge values in TBAs may become potential risk factors when combined with high population densities, as in north-eastern Africa, parts of the Middle East and Northern India and Pakistan. In these areas, return flows from irrigation and other human-induced recharge appear to play a major role in the sustainability of the groundwater resources utilization, adding a further element of vulnerability.

Groundwater depletion

Aquifers with the highest groundwater depletion rates worldwide are not transboundary. A comparison of aggregated and grid-based results reveals that most TBAs are located outside of the major groundwater depletion regions of the world.

In fact, mean annual groundwater depletion depths are Very Low to Low in most country segments. Medium to high depletion rates were computed in only three country segments, the Neogene Aquifer System in Syria, the Indus River Plain aquifer in India, and the merged Umm er Radhuma-Dammam Aquifer System in Bahrain, of 53 mm/yr, 28 mm/yr, and 222 mm/yr, respectively. Indicators computed for the country segment in Bahrain, however, are highly uncertain because of the small area of the country segment (535 km²).

Also, the identified groundwater depletion rate in the Indian part of the Indus River Plain aquifer seems inconsistent at first glance, compared with the small negative value of indicator 4.2a (-9 per cent) indicating a mean annual increase in groundwater storage. This inconsistency is attributable to the level of aggregation over the whole country segments. The grid-based distribution of indicator 3.1 and 4.2a reveals that very high depletion rates only occur in the northeastern part of the aquifer; in the remaining area groundwater storage is increased (resulting in slightly negative net abstractions from groundwater aggregated over the TBA). Groundwater depletion rates of almost 300 mm/yr in the northeast, however, are not counterbalanced by the slightly negative values in the remaining area, resulting in a groundwater depletion depth of 28 mm/yr in the Indian part of the Indus River Plain aquifer and 10 mm/yr aggregated over the whole TBA.

Groundwater development stress

Most TBAs are located outside high groundwater-stress regions.

Country segments with groundwater withdrawals exceeding 50 per cent of renewable groundwater resources include aquifers located in northern Africa (Lake Chad basin aquifer, Taoudeni basin aquifer), the Arabian Peninsula (Tawil Quaternary Aquifer System, Saq-Ram Aquifer System) and India (South of Outer Himalayas aquifer, East Ganges River Plain aquifer). Other country segments suffering from groundwater development stress satisfy between 35 and 91 per cent of their water demand from groundwater. In 20 of 258 country segments, water withdrawals account for more than 20 per cent of groundwater recharge; 12 of them are characterized by a medium to high dependence on groundwater defined as the ratio of groundwater to total water abstraction >40% .

Eight additional country segments were identified with low groundwater development stress but potential “groundwater crowding”, that is a medium to very high dependence on groundwater (indicator 2.1 > 40 per cent) and low per-capita groundwater resources (indicator 1.2 < 1 000 m³/yr/cap and dependence on groundwater >40 per cent), These country segments are located in the Syr Darya aquifer (Uzbekistan), the Keta/Dahomey/Côtier basin aquifer (Nigeria, Togo, Benin, Ghana), the Mereb aquifer (Eritrea, Ethiopia), and the Aquifère du Rift (DR Congo).

Groundwater development stress is projected to generally increase (in 230 country segments by 2030 and in 240 by 2050). The number of country segments suffering from medium to very high groundwater development stress in either 2030 or 2050 under the worst-case climate and irrigation scenario is projected to increase from 20 to 58, comprising all hotspots under current conditions.

New hotspots are projected to develop mainly in Sub-Saharan Africa, China and Mexico. All country segment TBA-CUs identified as hotspots in 2010 on the basis of the “groundwater crowding” criterion (see above) in 2010, except the Aquifère du Rift, may experience at least medium groundwater development stress in 2030 or 2050.

The highest future groundwater development stress values, as well as the largest increases of groundwater development stress of up to 40 percentage points, are projected for TBA country segments located in Botswana, the Middle East and North Africa region, South Asia, Uzbekistan, and Yucatán.

In the projections, eight new country segments were identified as potential hotspots on the basis of the “groundwater crowding” criterion, all of them in West or East Africa.

Population density, recharge and natural quality

In north-eastern Africa, parts of the Middle East and Northern India and Pakistan, low recharge values in TBAs are combined with high population densities. In these areas, return flows from irrigation and other human-induced recharge appear to play a major role in the sustainability of the groundwater resource utilization. Very Low natural quality (< 20 per cent of the aquifer area) coincides with TBAs highly impacted by irrigation return flows in densely populated areas with low to medium natural recharge, such as the Nubian, Indus, and Pre-Caspian TBAs.

Aquifer Buffering Capacity

High residence times of groundwater, over 100 years and up to more than 1 000 years, are reported for a number of country segments of TBAs in the Sahel and Saharan Africa, Central and South Asia, where aquifer capacity to mitigate the effects of prolonged droughts is highly valuable.

Governance

When focusing on the most probable causes of tension among TBA countries (notably, drawdown of groundwater levels, groundwater contamination from point and non-point sources of pollution and salinization/saltwater intrusion, man-made interference with natural groundwater recharge processes) the TBAs exhibiting a combination of no transboundary legal agreement or organization in place (the vast majority), and limited ‘implementation measures’ at the domestic level are, on paper at least, those most at risk of conflict.

At the global level, only eight TBAs have transboundary legal agreements. The patchy evidence on record prevents a serious juxtaposition of TBA-specific transboundary indicators and domestic ‘implementation measures’ indicators, and a resulting determination of which TBAs are more at risk of conflict than others.

It is clear, however, that the TBAs most at risk are those that exhibit actual or potential tension (for example groundwater development stress hotspots) and have no transboundary legal agreement or organization in place.

3.3.2. Discussion on High-risk Areas

High-risk areas: hotspots of current groundwater stress

Groundwater development stress (4.2), when combined with high human dependence on groundwater (2.1) and low per-capita renewable groundwater resources (1.2) leads to situations of high risk for groundwater sustainability and human health. Table 3.2 shows these three indicators grouped into three High Risk TBA Clusters: 1) TBA-country segments with medium to very high groundwater development stress and high human dependence on groundwater; 2) TBA-country segments with medium to very high groundwater development stress and low human dependence on groundwater; 3) TBA-country segments with low groundwater development stress but low per-capita groundwater resources and medium to very high human dependence on groundwater (“groundwater crowding”). Per-capita groundwater resources (indicator 1.2) are also mostly low in the first two of all three clusters.

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Table 3.2. High risk TBA Clusters under current conditions

Aquifer name	Country Segment	Current-state indicators		
		Renewable groundwater per capita (1.2)	*Human dependence on groundwater (2.1)*	*Groundwater development stress (4.2)*
		[mm/yr/cap]	[%]	[%]
1. "Very high risk": groundwater development stress (4.2) > 20% and dependence on groundwater (2.1) > 40%				
Lake Chad Basin	Libya	666	91	346
Northwest Sahara Aquifer System (NWSAS)	Libya	1 315	74	37
AS126_AS129 1)	Saudi Arabia	823	73	276
	Jordan	398	43	32
Neogene Aquifer System (North-West): Upper and Lower Fars	Syria	621	70	137
AS131_ 2)	Yemen	387	47	42
South of outer Himalayas aquifer	India	266	45	82
East Ganges River Plain aquifer	India	286	36	51
	Bangladesh	323	55	47
Edwards-Trinity-El Burro aquifer	USA	4 280	63	27
2. "High risk": groundwater development stress (4.2) > 20% and dependence on groundwater (2.1) < 40%				
Taoudeni Basin aquifer	Algeria	5	16	156
Irhazer-Illuemeden Basin aquifer	Algeria	17	17	50
AS127_ 3)	Kuwait	59	2	32
AS131_ 2)	Qatar	101	3	29
	Bahrain	17	15	876
Indus River Plain aquifer	Pakistan	809	18	36
Tacheng Basin / Alakol aquifer	China	11 103	11	21
Illi River aquifer	China	2 594	11	20
3. "Groundwater crowding": groundwater development stress < 20%, dependence on groundwater (2.1) > 40% and per capita groundwater resources (1.2) < 1 000 m^3/yr/cap				
Syr Darya aquifer	Uzbekistan	558	50	20
Keta/Dahomey/Cotier basin aquifer	Nigeria	240	49	11
	Togo	256	71	8
	Benin	467	80	5
	Ghana	316	50	5
Mereb aquifer	Ethiopia	414	52	4
	Eritrea	436	53	4
Aquifère du Rift	DR Congo	432	42	2

1) AS126_AS129: Tawil Quaternary Aquifer System: Wadi Sirhan Basin, etc.

2) AS131_AS139_AS140_AS141_fractionAS128: Umm er Radhuma-Dammam Aquifer System (South), etc.

3) AS127_AS130_fraction AS128: Wasia-Biyadh-Aruma Aquifer System (North): Sakaka-Rutba, etc.

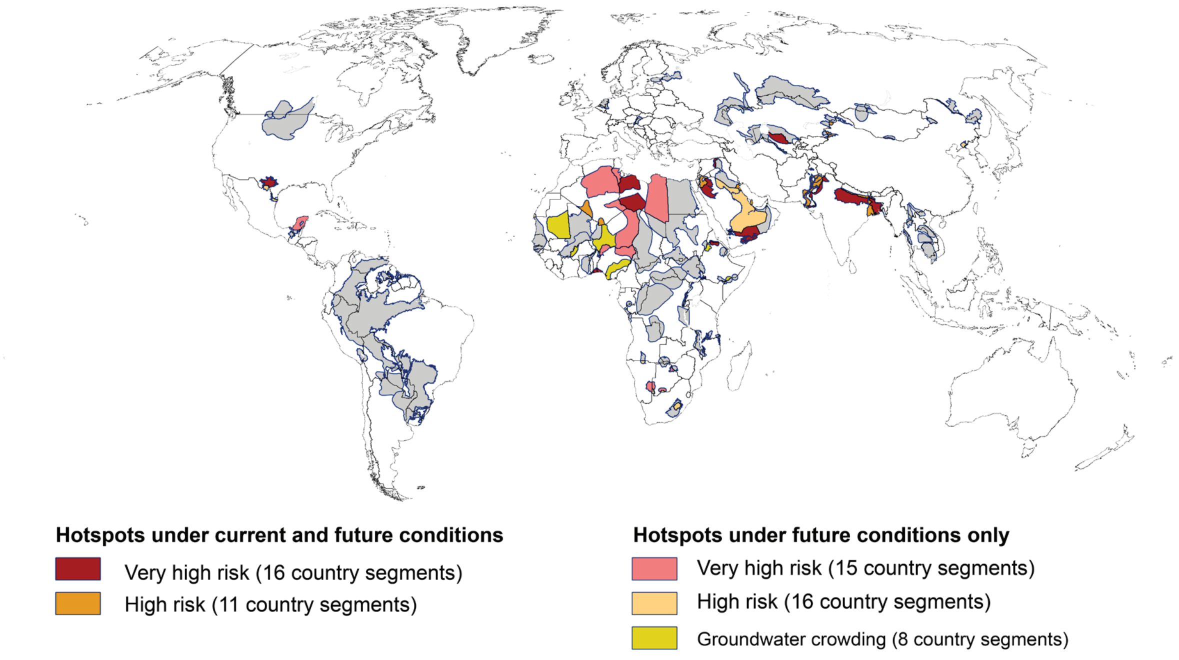
High-risk areas: hotspots of future groundwater stress

Hotspots in 2030 or 2050 were identified using the following criteria:

- Selection based on indicators 4.2 and 2.1 (Table 3.3, Figure 3.46): in all four scenarios, computed increases in groundwater development stress based on at least one GCM would lead to a medium or higher degree of groundwater development stress (indicator 4.2 > 20 per cent). Furthermore, dependence on groundwater is at least 40 per cent for at least one of the four scenarios based on the individual GCMs. Thus, hotspots of groundwater stress are identified on the basis of the worst-case scenario.
- Selection based on indicators 4.2 and 2.1 (Table 3.4, Figure 3.46): TBA-country segments meet the first criterion of indicator 4.2 > 20 per cent, but dependence on groundwater is low (indicator 2.1 < 40 per cent).
- Selection based on indicators 1.2 and 2.1 (Table 3.5): TBA-country segments that were not identified as being under groundwater development stress but where per-capita groundwater resources are less than 1 000 m³/yr/capita) and the dependence on groundwater exceeds 40 per cent ("groundwater crowding"), TBA-country segments were selected by taking the largest computed decreases (indicator 1.2) and increases (indicator 2.1) of all four scenarios and individual GCMs.

All TBA-country segments dentified as hotspots under current conditions (see Table 3.2) were also identified as hotspots under projected conditions except the Aquifère du Rift in the Democratic Republic of the Congo, where the dependence on groundwater is projected to reduce to less than 40 per cent.

Figure 3.46. Potential future hotspots of groundwater development stress (indicator 4.2) at the TBA country segment level using a worst-case scenario approach.



See Table 3.2 for definitions of hotspot risk classification. All eight country segments with "groundwater crowding" in current conditions suffer from development stress >20% under future conditions and are thus classified in the "Very high risk" category (current and future conditions).

In total, 31 of 258 TBA-country segments (12 per cent) extending over 21 TBAs show current or future groundwater stress with a high dependence on groundwater (Table 3.3, Figure 3.43)[24].

Two-thirds of the identified hotspots are located on the African continent and the Arabian Peninsula. The remaining TBA-country segments are distributed over Asia (Pakistan, India, Nepal, China, DPR Korea), and America (USA, Mexico, Chile). Also, the level of groundwater development stress (indicator 4.2) in the Austrian share of the Upper Pannonian Thermal aquifer is projected to rise above 20 per cent on the basis of results for at least one GCM (Table 3.2).

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[24] Projections for indicator 4.2a result in 24 TBA-country segments extending over 16 TBAs. When comparing the hotspots characterized by a low computed dependency on groundwater, indicator 4.2 results in 27 TBA-country segments (and 22 TBAs), while 17 TBA-country segments (and 14 TBAs) were identified using indicator 4.2a.

Table 3.3. TBA-Country segments under medium to very high groundwater development stress (indicator 4.2>20%) and a dependence on groundwater of >40% in 2030 and/or 2050 identified using individual GCM results representing the, worst-case scenario'.

In the third column, 2010 values of groundwater development stress are given in percentages. The columns to the right show changes of groundwater development stress in percentage points, both ensemble means (EM) and minimum/maximum values of individual GCMs. Darker colours indicate progressively higher projected percentage point changes of values of indicator 4.2.

Aquifer name	Country segments	WFD 2010	Changes in GW development stress relative to 2010 as computed by each GCM in percentage points											
			2030 AAI constant			2030 LandSHIFT			2050 constant			2050 LandSHIFT		
			EM	*min*	*max*	EM	*min*	*max*	EM	*min*	*max*	EM	*min*	*max*
SE Kalahri Karoo Basin/ Stampriet Artesian Aquifer System	Namibia	2.0	**3.3**	*-198*	*122*	**78**	*-250*	*568*	**-14.6**	*-200*	*127*	**65**	*-251*	*652*
	Botswana	0.4	**-508**	*-2 521*	*0*	**-508**	*-2 521*	*0*	**-1 177**	*-6 032*	*168*	**-1 177**	*-6 032*	*168*
Eastern Kalahari Karoo Basin	Botswana	0.7	**0.7**	*-2.0*	*5.1*	**0.7**	*-2.0*	*5.1*	**8.3**	*-1.0*	*36.6*	**8.3**	*-1.0*	*36.6*
Khakhea/Bray Dolomite	Botswana	1.0	**245**	*-47*	*1 263*	**315**	*-47*	*1 613*	**54**	*0.4*	*226*	**64**	*0.4*	*275*
Keta/Dahomey/Cotier basin aquifer	Ghana	4.9	**5.8**	*3.7*	*9.1*	**5.8**	*3.7*	*9.1*	**43.5**	*30.0*	*79.2*	**43.6**	*30.0*	*79.5*
	Benin	5.0	**4.5**	*3.5*	*5.1*	**4.5**	*3.5*	*5.1*	**35.6**	*28.7*	*44.9*	**35.6**	*28.7*	*44.9*
	Togo	8.2	**5.9**	*3.5*	*9.0*	**5.9**	*3.5*	*9.0*	**56.4**	*39.1*	*94.4*	**56.4**	*39.1*	*94.4*
	Nigeria	10.8	**16.2**	*14.7*	*18.4*	**16.2**	*14.7*	*18.4*	**70.8**	*64.3*	*76.5*	**70.8**	*64.3*	*76.5*
Lake Chad Basin	Nigeria	1.7	**2.7**	*0.9*	*4.7*	**2.8**	*0.9*	*4.8*	**14.2**	*6.3*	*25.3*	**14.2**	*6.3*	*25.4*
	Niger	1.2	**0.8**	*-0.2*	*2.4*	**0.8**	*-0.2*	*2.4*	**7.8**	*1.7*	*22.2*	**7.9**	*1.7*	*22.3*
	Algeria	19.1	**8.8**	*-26.9*	*79.1*	**13.4**	*-24.7*	*90.1*	**13.3**	*-20.4*	*57.4*	**16.8**	*-19.5*	*63.6*
	Libya	346.3	**-17.4**	*-65.7*	*4.2*	**-15.9**	*-56.8*	*3.8*	**-7.9**	*-29.9*	*13.9*	**-7.6**	*-26.2*	*12.6*
Irhazer-Illuemeden Basin	Nigeria	1.9	**2.9**	*1.4*	*4.1*	**3.0**	*1.5*	*4.1*	**14.4**	*8.3*	*19.5*	**14.4**	*8.3*	*19.6*
Northwest Sahara Aquifer System (NWSAS)	Algeria	12.7	**2.8**	*1.4*	*6.4*	**0.3**	*-0.9*	*3.4*	**4.9**	*2.2*	*10.1*	**1.3**	*-1.0*	*5.7*
	Tunisia	8.2	**3.1**	*0.9*	*9.7*	**-1.0**	*-2.2*	*3.0*	**5.4**	*1.4*	*15.3*	**0.2**	*-2.5*	*6.1*
	Libya	36.6	**7.8**	*0.3*	*27.8*	**14.2**	*5.8*	*36.1*	**15.6**	*0.7*	*47.6*	**20.2**	*4.6*	*54.0*
Afar Rift valley / Afar Triangle aquifer	Eritrea	3.6	**1.7**	*-1.0*	*4.4*	**1.7**	*-1.0*	*4.4*	**24.8**	*7.3*	*45.4*	**24.8**	*7.3*	*45.4*
Mereb	Eritrea	3.6	**3.7**	*0.6*	*6.7*	**4.1**	*0.8*	*7.1*	**26.8**	*11.2*	*36.2*	**26.7**	*11.3*	*35.9*
	Ethiopia	3.9	**16.9**	*11.9*	*22.7*	**16.9**	*11.9*	*22.7*	**57.1**	*40.1*	*73.2*	**57.0**	*40.0*	*73.0*
Nubian Sandstone Aquifer System (NSAS)	Libya	11.5	**2.3**	*0.8*	*3.6*	**4.1**	*2.4*	*5.7*	**4.5**	*2.9*	*7.7*	**5.9**	*4.1*	*9.4*
AS126_AS129	Saudi Arabia	276	**0.5**	*-15.3*	*23.4*	**-3.4**	*-19.6*	*19.4*	**21.7**	*-3.8*	*52.3*	**15.3**	*-12.2*	*46.0*
Neogene Aquifer System (North-West): Upper and Lower Fars	Syria	137	**23.3**	*15.2*	*31.5*	**13.9**	*5.3*	*22.9*	**40.4**	*23.6*	*55.1*	**25.2**	*5.7*	*43.3*
AS131_	Yemen	41.9	**-4.9**	*-18.2*	*7.9*	**7.9**	*-6.2*	*21.0*	**8.2**	*-7.8*	*41.0*	**15.9**	*0.6*	*48.1*
Upper Pannonian Thermal aquifer	Austria	15.9	**2.0**	*-0.4*	*3.6*	**1.8**	*-0.6*	*3.4*	**2.8**	*0.9*	*4.9*	**2.3**	*0.5*	*4.2*
Syr Daria	Uzbekistan	19.5	**10.9**	*-5.5*	*32.5*	**11.3**	*-5.4*	*33.3*	**15.1**	*-12.8*	*42.3*	**15.7**	*-12.7*	*43.6*
Indus River Plain aquifer	India	35.2	**10.0**	*-0.1*	*18.2*	**12.4**	*2.7*	*19.2*	**17.8**	*7.1*	*29.5*	**19.4**	*9.2*	*31.3*
South of outer Himalayas aquifer	India	81.8	**13.8**	*1.9*	*23.5*	**20.0**	*8.4*	*30.1*	**20.9**	*10.6*	*40.6*	**25.9**	*16.2*	*45.3*
East Ganges River Plain aquifer	Bangladesh	47.4	**7.8**	*3.7*	*11.7*	**0.1**	*-3.1*	*3.4*	**18.3**	*13.9*	*21.1*	**8.9**	*5.5*	*11.4*
Dankhan Khudgiin Sair aquifer	China	5.5	**4.0**	*-1.0*	*20.6*	**3.5**	*-1.3*	*19.2*	**4.6**	*-1.0*	*21.4*	**4.0**	*-1.4*	*19.8*
Península de Yucatán-Candelaria-Hondo	Mexico	4.8	**7.1**	*1.9*	*17.8*	**7.6**	*2.3*	*18.6*	**14.2**	*3.4*	*28.4*	**14.8**	*3.7*	*29.4*
Edwards-Trinity-El Burro	USA	26.6	**10.9**	*-0.3*	*23.5*	**5.8**	*-4.7*	*18.3*	**7.0**	*2.7*	*15.5*	**0.8**	*-4.2*	*10.4*

Table 3.4. TBA Country segments under medium to very high groundwater development stress (indicator 4.2>20%) and a dependence on groundwater of <40% in 2030 and/or 2050 identified using individual GCM results representing the, worst-case scenario'

In the third column, 2010 values of groundwater development stress are given in percentages. The columns to the right show changes of groundwater development stress in percentage points, both ensemble means (EM) and minimum/maximum values of individual GCMs. Darker colours indicate progressively higher projected percentage point changes of values of indicator 4.2.

Aquifer name	Country segment	WFD	Changes in GW development stress relative to 2010 as computed by each GCM in percentage points											
			2030 AAI constant			2030 LandSHIFT			2050 constant			2050 LandSHIFT		
			EM	min	max	EM	min	max	EM	min	max	EM	min	max
SE Kalahri Karoo Basin/ Stampriet Artesian Aquifer System	South Africa	0.1	18	-113	192	18	-113	192	53	-3	162	53	-3	162
Khakhea/Bray Dolomite	South Africa	0.4	0.0	-15.6	14.8	4.3	-15.7	36.6	3.9	-4.2	23.7	0.0	-4.4	4.4
Karoo Sedimentary Aquifer	Lesotho	4.2	2.3	1.4	3.4	2.3	1.3	3.4	21.1	18.4	24.5	21.0	18.4	24.4
Cuvelai and Ethosa Basin/ Ohangwena Aquifer System	Namibia	1.4	20.4	0.2	52.4	20.4	0.2	52.4	46	-0.7	196	46	-0.7	196
Aquifère du Rift	Rwanda	2.8	11.0	8.0	12.0	11.0	8.0	12.0	30.5	20.1	38.5	30.5	20.1	38.5
	South Sudan	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.2	0.1	0.0	0.2
	Uganda	1.0	4.3	2.1	7.6	4.3	2.1	7.6	13.3	5.5	25.8	13.3	5.5	25.8
Dawa	Kenya	1.8	5.8	1.9	10.6	6.2	2.0	11.4	13.2	3.6	29.7	11.9	3.5	25.7
Senegalo-Mauretanian Basin	Western Sahara	3.6	-10 355	-52 271	813	-10 355	-52 271	813	no value	-52 271	167	no value	-52 271	167
Irhazer-Illuemeden Basin	Algeria	49.6	2.0	-0.4	9.7	2.0	-0.4	9.7	10.9	-0.3	51.0	10.9	-0.3	51.0
Taoudeni Basin	Algeria	156.0	-1 786	-8 096	-14	-1 786	-8 096	-14	-586	-7 964	5 487	-586	-7 964	5 487
AS131_	Bahrain	876.3	394	82	1028	495	120	1 268	993	425	2103	822	363	1 693
	Qatar	29.3	-0.5	-12.3	29.0	5.1	-8.4	38.4	11.2	1.4	42.7	5.9	-3.8	34.7
	Saudi Arabia	13.4	0.1	-5.7	6.9	-0.7	-6.6	6.0	2.5	-1.5	8.0	4.3	0.8	10.1
AS127_	Kuwait	32.2	-2.3	-8.9	4.7	-9.5	-15.9	-2.3	-7.7	-15.4	1.3	4.9	-3.6	14.3
	Saudi Arabia	18.9	1.3	-3.5	6.1	0.6	-4.2	5.4	9.8	2.3	20.1	11.8	3.9	22.3
AS126_AS129	Jordan	32.0	19.4	10.0	28.8	17.4	8.3	26.5	41.7	23.7	56.4	44.7	26.2	59.9
Indus River Plain aquifer	Pakistan	36.4	2.2	-0.8	3.4	1.2	-2.0	2.3	7.0	4.3	8.0	7.7	5.4	8.8
East Ganges River Plain	India	51.2	8.2	3.6	11.7	12.0	6.5	15.8	14.5	9.9	18.3	11.7	7.1	15.4
South of outer Himalayas aquifer	Nepal	22.0	3.0	1.3	3.8	5.0	3.3	5.8	10.8	8.4	13.3	9.3	6.9	11.6
Yalu River Basin	China	10.5	9.5	8.6	11.8	9.8	8.9	12.0	11.7	10.2	13.8	11.6	10.0	13.6
Illi River	China	20.1	0.3	-0.1	0.5	0.2	-0.1	0.5	0.4	0.0	0.8	0.4	0.1	0.8
Tacheng Basin / Alakol	China	20.5	0.0	-0.1	0.1	0.0	-0.2	0.1	0.0	-0.1	0.1	0.0	-0.1	0.1
Yalu River Basin	DPR Korea	12.7	8.1	6.8	9.8	8.7	7.3	10.3	9.4	8.2	11.1	9.0	7.6	10.8
Edwards-Trinity-El Burro	Mexico	13.5	5.8	-7.2	13.5	7.4	-5.9	15.0	14.8	4.5	24.9	13.7	3.5	23.6
Cuenca Baja del Río Bravo-Grande	Mexico	8.2	5.8	4.2	7.4	5.1	3.7	6.4	7.8	5.3	10.5	8.8	6.1	12.2
Titicaca	Chile	8.8	5.9	-0.9	12.2	5.3	-1.8	12.1	14.4	1.3	26.6	14.7	2.3	26.5

NO VALUE: DIVIDED BY ZERO (GROUNDWATER RECHARGE = 0)

Table 3.5. Groundwater crowding (indicators 1.2 and 2.1), TBA Country segments with low groundwater development stress (indicator 4.2<20%), but with low per-capita groundwater recharge (indicator 1.2<1000 m^3/yr/capita) and a dependence on groundwater of >40% (indicator 2.1)

In 2030 and/or 2050 identified using individual GCM results representing the 'worst-case scenario'. In the third column, 2010 values of per-capita groundwater recharge are given in m³/yr/capita. The columns to the right show changes of per-capita groundwater recharge in percentages, both ensemble means (EM) and mini- mum/maximum values of individual GCMs.

Aquifer name	**Country segment**	**WFD**	**Changes in per-capita GW recharge relative to 2010 as computed by each GCM in percentage points**											
			2030 AAI constant			**2030 LandSHIFT**			**2050 constant**			**2050 LandSHIFT**		
			EM	*min*	*max*	**EM**	*min*	*max*	**EM**	*min*	*max*	**EM**	*min*	*max*
Taoudeni Basin	Mauritania	2151	**3**	*-31*	*85*	**3**	*-31*	*84*	**-21**	*-62*	*66*	**-21**	*-62*	*66*
Volta Basin	Burkina Faso	3221	**-28**	*-52*	*23*	**-28**	*-52*	*23*	**-56**	*-79*	*-11*	**-56**	*-79*	*-11*
Aquifer extension Sud-Est de Taoudeni	Burkina Faso	1686	**-34**	*-53*	*-2*	**-34**	*-53*	*-2*	**-60**	*-77*	*-30*	**-60**	*-77*	*-30*
Aquifère Vallée de la Bénoué	Nigeria	1476	**-39**	*-44*	*-34*	**-39**	*-44*	*-34*	**-62**	*-65*	*-56*	**-62**	*-64*	*-56*
	Cameroon	2895	**-34**	*-44*	*-23*	**-34**	*-44*	*-24*	**-58**	*-70*	*-48*	**-58**	*-70*	*-48*
Irhazer-Illuemeden Basin	Niger	1482	**-30**	*-45*	*1*	**-30**	*-45*	*1*	**-59**	*-75*	*-32*	**-59**	*-75*	*-32*
Jubba	Ethiopia	1606	**-16**	*-49*	*8*	**-16**	*-49*	*8*	**-16**	*-49*	*24*	**-15**	*-49*	*24*
Gedaref	Ethiopia	1433	**-19**	*-30*	*2*	**-19**	*-30*	*2*	**-34**	*-44*	*-9*	**-34**	*-44*	*-9*

References

Eckstein, G. E., & Sindico, F. (2014). The law of transboundary aquifers: Many ways of going forward, but only one way of standing still. Review of European, Comparative and International Environmental Law, 23(1), 32–42.

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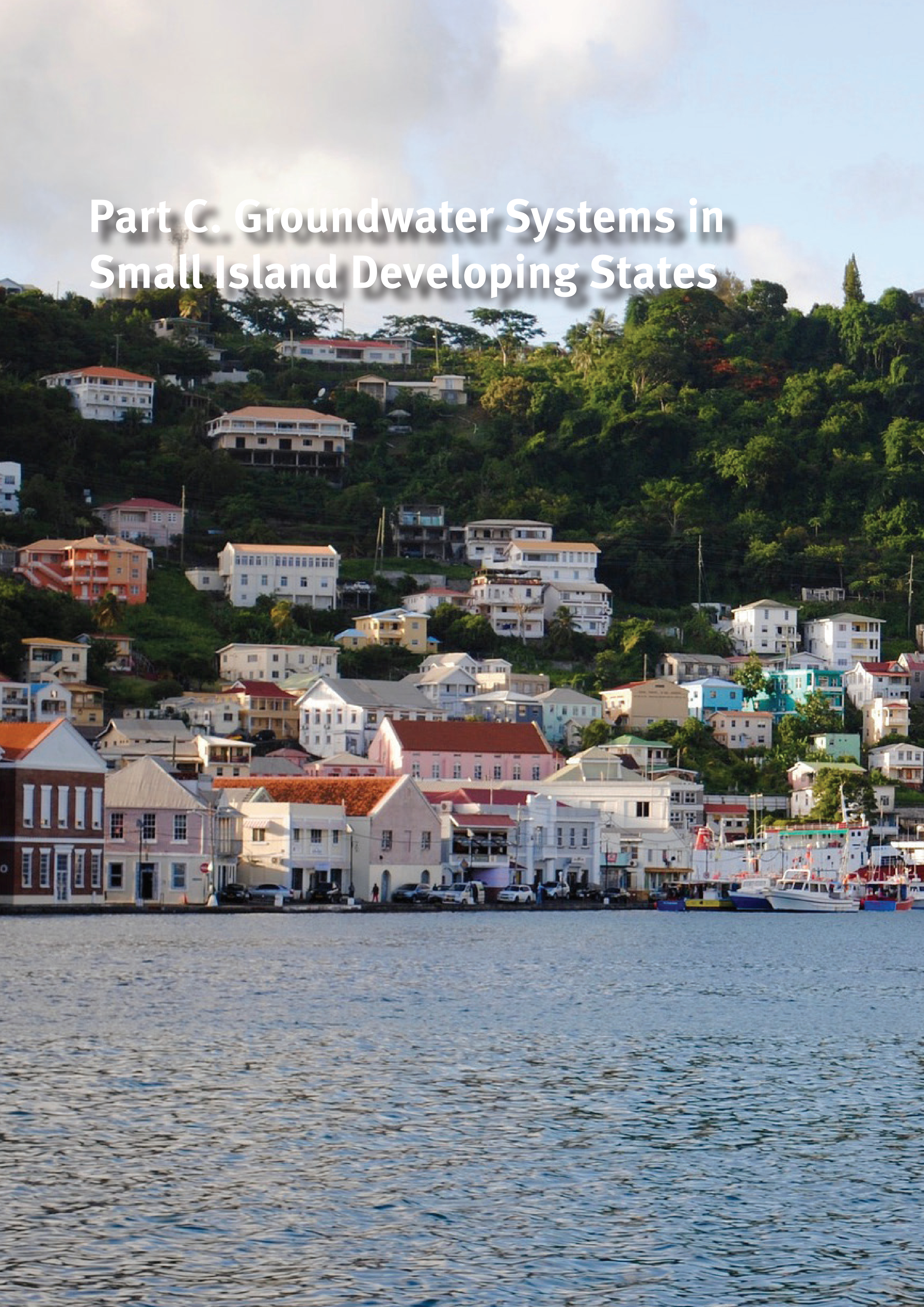
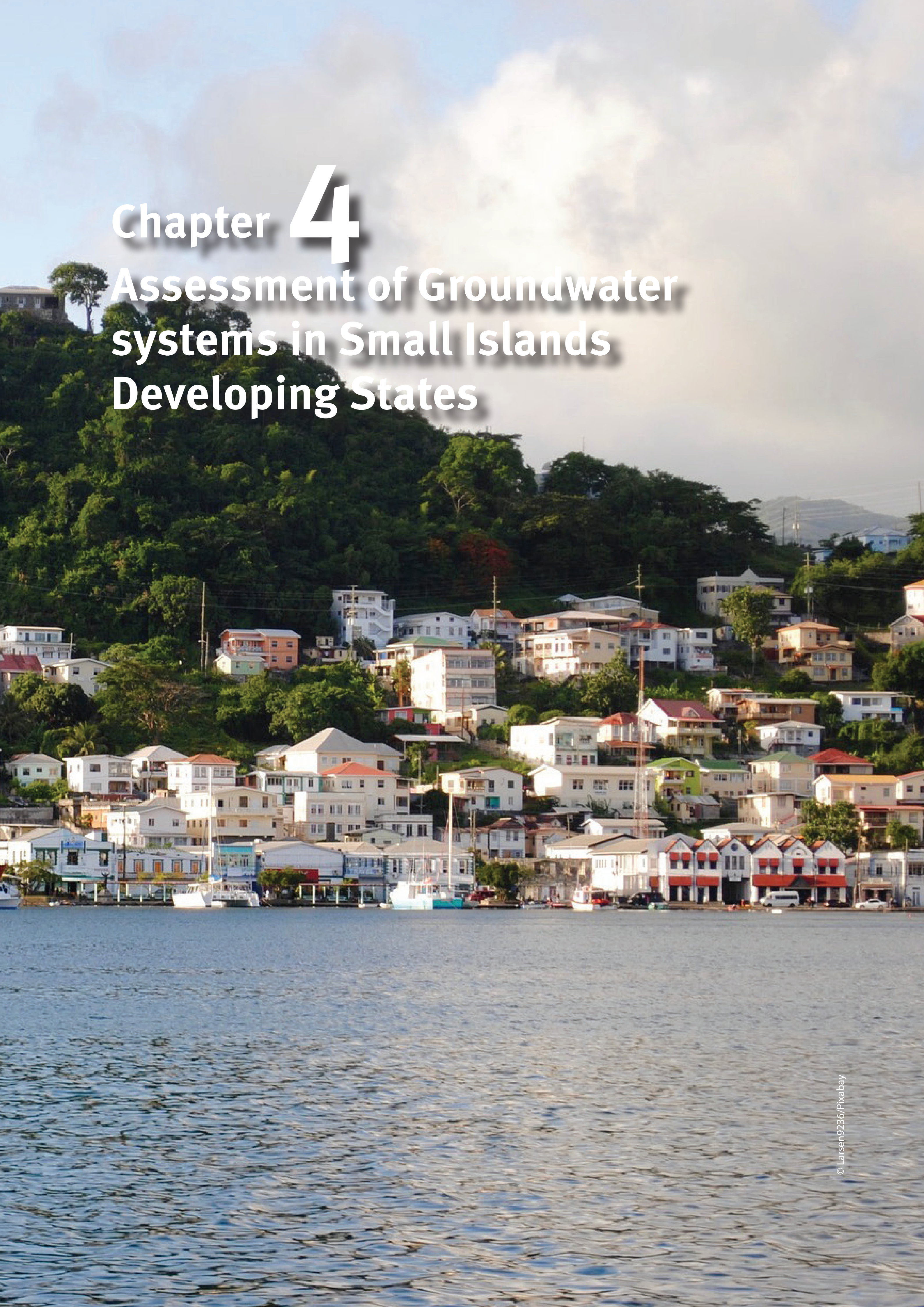
Part C. Groundwater Systems in Small Island Developing States



Chapter 4

Assessment of Groundwater systems in Small Islands Developing States



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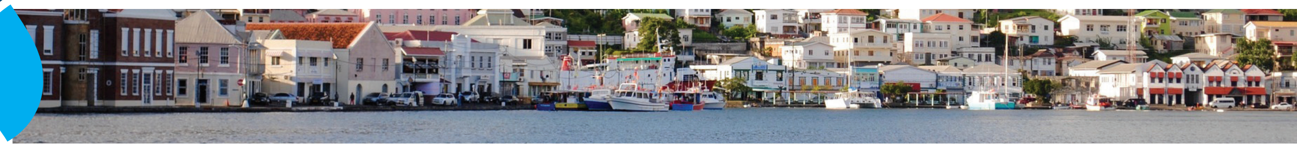
Chapter Citation: Allen, D., Holding, S., Carvalho-Resende, T., Merla, A., Nijsten, G.J. (2016). Chapter 4: Assessment of Groundwater systems in Small Islands Developing States. In UNESCO-IHP and UNEP (2016). Transboundary Aquifers and Groundwater Systems of Small Island Developing States Status and Trends. United Nations Environment Programme, Nairobi, pp. 105-113.

4. Assessment of Groundwater systems in Small Islands Developing States



This section summarizes the methodology and results for the Assessment of Groundwater Systems of Small Island Developing States (SIDS) carried out as part of the GEF Transboundary Water Assessment Programme (TWAP) – Groundwater (Allen et al. 2015). The assessment focuses on 42 SIDS (see Table 4.1). The assessment, which takes the whole island state as the primary spatial unit, includes aquifer properties and time-dependent variables that were compiled from the literature, modelling, and the results of questionnaires sent to national experts. A suite of indicators, common to the TWAP TBAs assessment (Table 2.3), was evaluated on the basis of the above information. For each SIDS, a hydrogeological profile has been developed consisting of a geological map and cross-section, and key summary information concerning the hydrogeology.

SIDS' are all island developing countries and territories with a population of less than 5 million people. While both the UN and the Commonwealth Secretariat use population as the benchmark, there is no officially agreed international definition of smallness. Factors such as small size (land and population), insularity and remoteness, limited natural resource base and problems associated with the local environment are all obstacles to achieving efficiency in livelihood development, economic production, environmental sustainability and climate change adaptation.

4.1. Identification of SIDS aquifer systems for the assessment

Given the high level of human dependence on groundwater in SIDS, the assessment will also encompass aquifers in SIDS, irrespective of whether they are or are not transboundary.

An overview of the world's SIDS, according to the SIDS portal of UNDESA, lists 51 SIDS, 4 of which are on continents and some are not really small (4 are larger than 50 000 km^2), while 4 have more than 5 million inhabitants. Three criteria have been chosen as appropriate to reduce the number of SIDS to be included in the TWAP aquifer assessment. The first is size; setting a maximum of 50 000 km^2 eliminates four countries: Cuba, Guyana, Suriname and Papua New Guinea. The second is that the state should consist of one or more islands (or part of islands) and not be located on a continent; this deletes another two countries: Guinea-Bissau and Belize. Taking as a third criterion that the number of inhabitants should not exceed 5 million leads to also deleting the Dominican Republic and Haiti. Combining these criteria reduces the number to be included in TWAP from 51 to 42.

4.2. Objectives and Methodology

The aim of this project is to assess (quantitatively or qualitatively) the set of pre-defined TWAP groundwater indicators for each SIDS. The research consisted of the following steps:

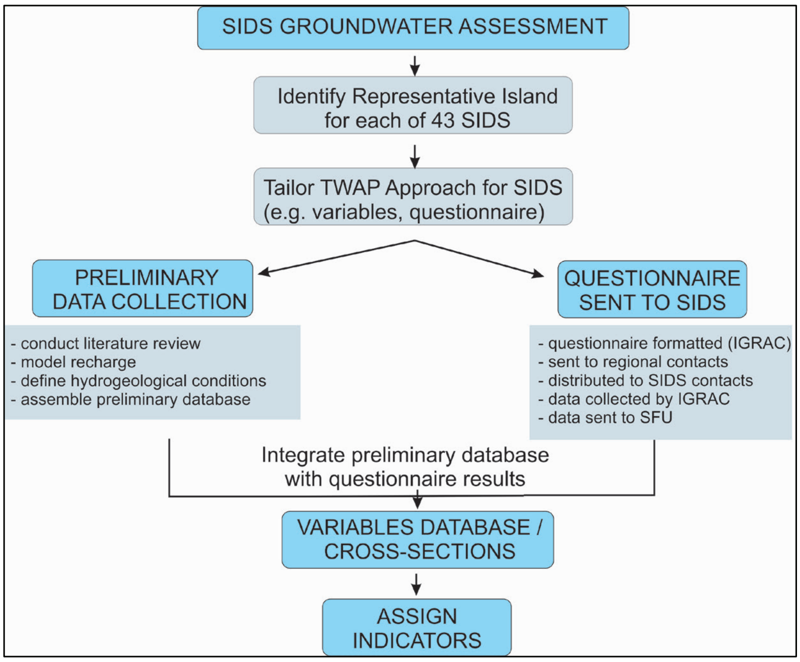
- **Conduct a preliminary assessment of variables** by compiling data and information from publications and existing (and accessible) datasets. The approach, as far as possible, used a consistent methodology for assessing all the SIDS as a group.
- **Develop and distribute of a questionnaire** to regional expert networks and knowledgeable experts on groundwater resources within each SIDS.

Table 4.1. List of target islands for SIDS assessment

State	Target Island	Population of Island (year)	Terrain
AIMS Region (6 SIDS):			
Cape Verde	Santiago	240 000 (2010)	Rugged, rocky, volcanic
Comoros	Njazidja	316 600 (2006)	Volcanic islands
Maldives	Male	105 000 (2012)	Coral limestone
Mauritius	Mauritius	1 236 817 (2011)	Volcanic, mountainous
Sao Tome and Principe	Sao Tome	157 500 (2011)	Volcanic, mountainous
Seychelles	Mahe	78 539 (2010)	Volcanic, sands
Caribbean (17 SIDS):			
Anguila	Anguila	13 452 (2011)	Flat low-lying coral and limestone
Antigua and Barbuda	Antigua	81 161 (2011)	Volcanic and low-lying limestone and coral
Aruba	Aruba	103 504 (2011)	Karstic Limestone
Barbados	Barbados	277 821 (2010)	Karstic Limestone
British Virgin Islands	Tortola	23 908 (2005)	Hilly volcanic islands and flat coral islands
Dominica	Dominica	71 293 (2011)	Rugged volcanic mountains
Grenada	Grenada	103 328 (2011)	Volcanic, mountainous
Jamaica	Jamaica	2 695 543 (2010)	Karstic limestone
Montserrat	Montserrat	5 164 (2012)	Volcanic mountains, coastal lowland
Netherlands Antilles	Curaçao	150 563 (2011)	Carbonates, volcanic interiors
Puerto Rico	Puerto Rico	3 725 789 (2010)	Volcanic, limestone
St Kitts and Nevis	Saint Christopher (i.e. Saint Kitts)	35 217 (2001)	Volcanic, mountainous interiors
Saint Lucia	Saint Lucia	165 770 (2010)	Volcanic, mountainous, broad valleys
Saint Vincent and the Grenadines	Saint Vincent and The Grenadines	106 253 (2001)	Volcanic, mountainous
The Bahamas	New Providence	248 948 (2010)	Karstic limestone
Trinidad and Tobago	Trinidad	1 267 145 (2011)	Limestone
US Virgin Islands	Saint Croix	50 601 (2010)	Limestone
The Pacific (19 SIDS):			
American Samoa	Tutuila	55 876 (2000)	5 volcanic islands, 2 coral atolls
Belau/Palau	Koror/Oreor	11 560 (2005)	Volcanic
C'wealth. of the Northern Marianas	Saipan	48 220 (2010)	S: limestone + reefs, N: volcanic
Cook Islands	Rarotonga	10 572 (2011)	N: low coral atolls; S: volcanic, hilly
Fiji	Viti Levu	661 997 (2007)	Volcanic mountains, coral atolls
French Polynesia	Tahiti	183 645 (2012)	Mix of rugged volcanic and low lying islands
Guam	Guam	159 358 (2010)	Limestone
Kiribati	Tawara/Kiritimati	40 529 (2010)	Limestone
Marshall Islands	Majuro	27 797 (2011)	Low coral limestone and sand
Federates States of Micronesia	Pohnpei	36 196 (2010)	Volcanic, mountainous, coral atolls
Nauru	Nauru	10 084 (2011)	Limestone
New Caledonia	Grande Terre	245 580 (2009)	Metamorphic and sedimentary
Niue	Niue	1 625 (2006)	Limestone cliffs, central plateau
Samoa	Upolu	143 418 (2011)	Basalt
Solomon Islands	Malaita	137 596 (2009)	Limestone, volcanic
Timor-Leste	Timor-Leste	1 066 582 (2010)	Limestone
Tonga	Tongatapu	75 416 (2011)	Karstic limestone
Tuvalu	Funafati	6 194 (2012)	Limestone
Vanuatu	Efate	65 829 (2009)	Limestone, volcanic

- Integrate the results of the questionnaire with the preliminary assessment of variables to **define the Current State Indicators.**
- **Assess links between water systems.** Within the context of SIDS, the most important link is between the aquifer and the ocean because of the potential for saltwater intrusion.
- Generate a hydrogeological profile for a representative island for each SIDS.
- Integrate GIS layers and the related database, summarizing the attributes of each SIDS, together with supporting references. Into the TWAP Groundwater Information Management System.

Figure 4.1. Workflow for the assessment of SIDS Groundwater Systems.



The 42 SIDS are situated within three regions: AIMS (Africa, Indian Ocean, Mediterranean and South China Sea); Caribbean; and Pacific. Thirty of the 42 SIDS comprised more than one island (up to 40 for French Polynesia). It was therefore not practical to collect information on an island-by-island basis. Instead, the strategy was to select one representative island within each SIDS. Typically, the representative island had the largest population. Table 4.1 shows the list of the 42 SIDS part of the assessment, and the respective representative islands.

4.3. Developing and distributing the questionnaire

The questionnaire was developed and distributed together with the preliminary assessment. The aim of the questionnaire was to collect information on the variables from knowledgeable experts for each SIDS. The aim was to supplement existing information with more detailed data for better definition of the Current State Indicators. The general TWAP questionnaire[25] and supporting guidance document were modified to include questions specific to islands (for example in relation to the freshwater lens), and remove questions specific to transboundary aquifers, since only the Timor-Leste aquifer is transboundary (a customized letter was sent to Timor-Leste to encourage submission of transboundary-related information).

The questionnaire and guidance documents were sent to all identified[26] regional coordinators or knowledgeable experts on groundwater resources within each SIDS.

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[25] UNESCO IHP developed a questionnaire specific to transboundary aquifers (www.twap.isarm.org).

[26] Details concerning this process, including return rates, are provided at 4.5.

4.4. Preliminary assessment

4.4.1. Compiling the variable database

The assessment approach used a consistent methodology for assessing all the SIDS as a group. The aim was to complete the assessment for all SIDS using a similar strategy, and filling in or modifying variables by seeking expert or local knowledge using the questionnaire. Unlike transboundary aquifer assessments, which cover larger areas, the SIDS are very small, with independent (not shared) aquifer systems that are confined to individual islands[27]. The data were therefore sourced initially from easily-accessible global and regional publications and existing and accessible databases as recommended in the TWAP Groundwater Methodology. The same global data sources were used, where possible, for acquiring population statistics, climate data and projections, and geo-referenced data (island boundaries, digital elevation models). Otherwise, information collected in the preliminary assessment derived from a variety of sources.

Hydraulic conductivity is a characteristic of the aquifer (variable), but is also needed for recharge estimation, as described below. Where a hydraulic conductivity estimate was not available from the literature for a particular SIDS, a representative value for the rock/sediment type was assigned. Actual Evapotranspiration (AET) and Recharge, current and projected, were estimated for all islands using a common approach[28].

4.4.2. Confidence Level

In the assessment, confidence level was assigned in order to capture the quality of the data. Each variable was assigned a level of confidence: high, medium or low, and the corresponding entries in the database colour-coded accordingly:

- High (green): where actual data are available (cited in a report and/or supported by questionnaire responses), a high confidence level was assigned. The information was recorded 'as is'. The available data are specific to the target island and of good quality.
- Medium (yellow): information was available on the specific variable, but generally this was only qualitative or the data were specific to one area of the target island or a limited period. Further interpretation was required to assign a numerical value or class to these variables.
- Low (red) : information and data are scarce, not specific to the specified period and/or the target island. Often these variables were estimated or extrapolated from information for a hydrogeologically similar SIDS.

4.4.3. Island hydrogeological profiles

A representative hydrogeological profile was generated for each SIDS, consisting of a location map, a generalized geological map and a representative cross-section. Also included on the hydrogeological profile are the relevant statistics: island area, maximum elevation, aquifer lithology, average annual precipitation, calculated AET, recharge, maximum aquifer thickness[29], groundwater volume, groundwater volume extracted, and predominant natural groundwater quality. The statistics are only provided for the dominant aquifer lithology, identified on the geological map legend. Alternative aquifer lithologies, if present, are listed in the statistics table, although no data are provided for them. Additionally, the shape of the freshwater lens is approximated on the basis of questionnaire results, if provided, for the near-coast hydrogeological setting. Thicker lenses are assumed to develop under high topography areas and these were approximated in the cross-sections[30].

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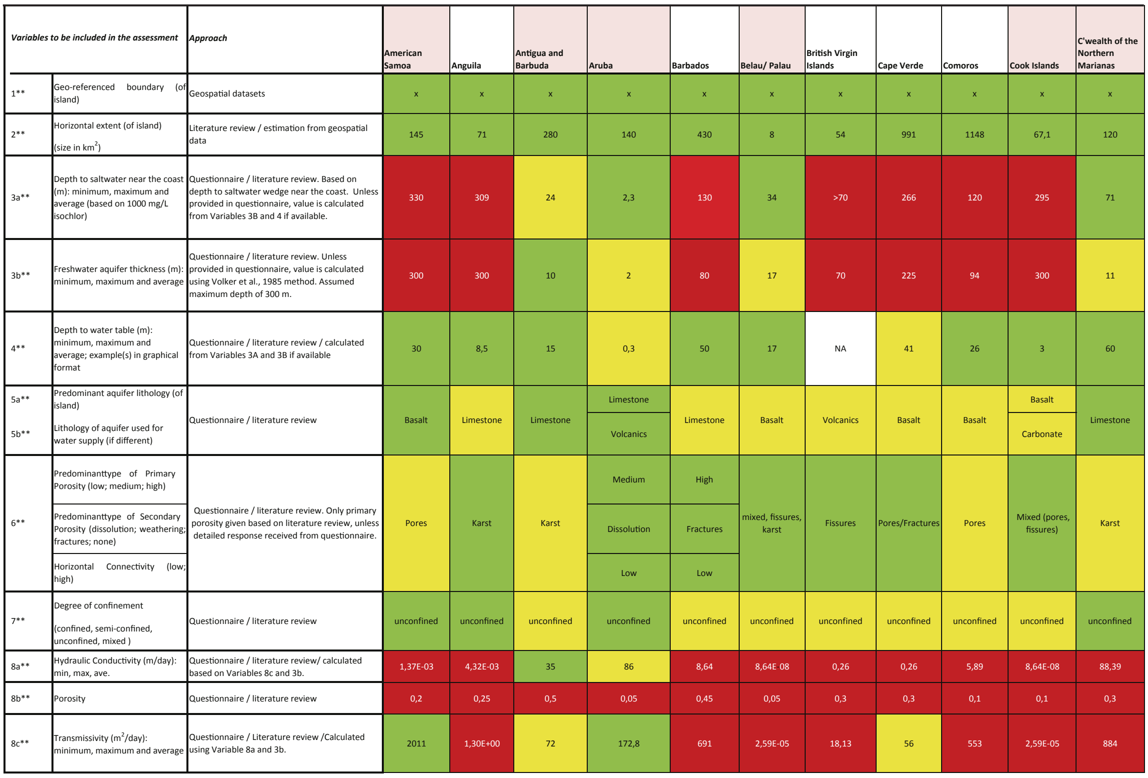
[27] The exception is Timor Leste, which is identified as a transboundary island aquifer.

[28] See Appendix 4 of the technical report "Assessment of SIDS Groundwater Systems" (Allen et al. 2015).

[29] On an island, the aquifer thickness coincides with the freshwater lens thickness.

[30] According to the Ghyben – Herzberg Principle, when fresh groundwater floats over saltwater, there are 40 feet of freshwater below sea level for every foot above sea level.

Figure 4.2. Screen capture of a portion of the variables database. The colours show confidence levels (green: high, yellow : moderate, red : low). Available at www.twap.isarm.org.



Variables to be included in the assessment		*Approach*	American Samoa	Anguila	Antigua and Barbuda	Aruba	Barbados	Belau/ Palau	British Virgin Islands	Cape Verde	Comoros	Cook Islands	C'wealth of the Northern Marianas
1**	Geo-referenced boundary (of island)	Geospatial datasets	🟩 x	🟩 x	🟩 x	🟩 x	🟩 x	🟩 x	🟩 x	🟩 x	🟩 x	🟩 x	🟩 x
2**	Horizontal extent (of island) (size in km^2)	Literature review / estimation from geospatial data	🟩 145	🟩 71	🟩 280	🟩 140	🟩 430	🟩 8	🟩 54	🟩 991	🟩 1148	🟩 67,1	🟩 120
3a**	Depth to saltwater near the coast (m): minimum, maximum and average (based on 1000 mg/L isochlor)	Questionnaire / literature review. Based on depth to saltwater wedge near the coast. Unless provided in questionnaire, value is calculated from Variables 3B and 4 if available.	🟥 330	🟥 309	🟨 24	🟩 2,3	🟥 130	🟩 34	🟥 >70	🟥 266	🟥 120	🟥 295	🟩 71
3b**	Freshwater aquifer thickness (m): minimum, maximum and average	Questionnaire / literature review. Unless provided in questionnaire, value is calculated using Volker et al., 1985 method. Assumed maximum depth of 300 m.	🟥 300	🟥 300	🟩 10	🟨 2	🟥 80	🟨 17	🟥 70	🟥 225	🟥 94	🟥 300	🟨 11
4**	Depth to water table (m): minimum, maximum and average; example(s) in graphical format	Questionnaire / literature review / calculated from Variables 3A and 3B if available	🟩 30	🟩 8,5	🟩 15	🟨 0,3	🟩 50	🟩 17	NA	🟨 41	🟩 26	🟩 3	🟩 60
5a**	Predominant aquifer lithology (of island)	Questionnaire / literature review	🟩 Basalt	🟨 Limestone	🟩 Limestone	🟩 Limestone	🟨 Limestone	🟨 Basalt	🟨 Volcanics	🟨 Basalt	🟨 Basalt	🟨 Basalt	🟩 Limestone
5b**	Lithology of aquifer used for water supply (if different)					🟩 Volcanics						🟨 Carbonate	
6**	Predominanttype of Primary Porosity (low; medium; high)	Questionnaire / literature review. Only primary porosity given based on literature review, unless detailed response received from questionnaire.	🟨 Pores	🟩 Karst	🟨 Karst	🟩 Medium	🟩 High	🟩 mixed, fissures, karst	🟩 Fissures	🟩 Pores/Fractures	🟨 Pores	🟩 Mixed (pores, fissures)	🟨 Karst
	Predominanttype of Secondary Porosity (dissolution; weathering; fractures; none)					🟩 Dissolution	🟩 Fractures						
	Horizontal Connectivity (low; high)					🟩 Low	🟩 Low						
7**	Degree of confinement (confined, semi-confined, unconfined, mixed)	Questionnaire / literature review	🟩 unconfined	🟩 unconfined	🟨 unconfined	🟩 unconfined	🟨 unconfined	🟨 unconfined	🟨 unconfined	🟨 unconfined	🟨 unconfined	🟨 unconfined	🟩 unconfined
8a**	Hydraulic Conductivity (m/day): min, max, ave.	Questionnaire / literature review/ calculated based on Variables 8c and 3b.	🟥 1,37E-03	🟥 4,32E-03	🟩 35	🟨 86	🟥 8,64	🟥 8,64E-08	🟥 0,26	🟥 0,26	🟥 5,89	🟥 8,64E-08	🟥 88,39
8b**	Porosity	Questionnaire / literature review	🟥 0,2	🟥 0,25	🟥 0,5	🟥 0,05	🟥 0,45	🟥 0,05	🟥 0,3	🟥 0,3	🟥 0,1	🟥 0,1	🟥 0,3
8c**	Transmissivity (m^2/day): minimum, maximum and average	Questionnaire / Literature review /Calculated using Variable 8a and 3b.	🟩 2011	🟥 1,30E+00	🟨 72	🟩 172,8	🟥 691	🟥 2,59E-05	🟥 18,13	🟨 56	🟥 553	🟥 2,59E-05	🟥 884

Significant effort was invested in the generation of these island profiles. A customized hydrogeological profile was generated for each SIDS. All island profiles are available at http://twapviewer.un-igrac.org. Examples are provided in Appendix 4.

4.4.4. Integrating the questionnaire responses with the preliminary assessment

The information provided by the experts was integrated with the preliminary assessment data. When questionnaire data were based on dedicated studies conducted within the predominant aquifer lithology, for example pumping tests, monitoring programs or recharge studies, the questionnaire values replaced the preliminary assessment data. This occurred mainly for variables such as depth and thickness of the freshwater lens, hydraulic conductivity, transmissivity, and groundwater/blue water abstraction rates. When questionnaire data were based on approximate values, for example recharge estimates based on percentages of total precipitation, the preliminary assessment data were used to ensure that a consistent methodology of approximation was applied. In cases where the questionnaire data corroborated the preliminary assessment data, a higher level of confidence was assigned to the variable. Variables based on the preliminary assessment data were re-calculated if a related variable was provided in the questionnaire results. For example, if the questionnaire results provided hydraulic conductivity, but not an estimate of aquifer thickness, recharge or groundwater volume, these variables were re-calculated using the SIDS-specific hydraulic conductivity value within the preliminary assessment methodology.

4.4.5. Assigning indicators

The TWAP Groundwater Methodology describes how links between the groundwater system and other water systems can be identified. Within the context of SIDS, the most important link is between the aquifer and the ocean, because of the potential for saltwater intrusion. Indicators relevant to this aspect of links were assessed both qualitatively and quantitatively. First, each island a hydrogeological cross-section (see Appendix 4) was constructed in such a fashion as to show the approximate depth of the saltwater-freshwater interface as a quantitative, although uncertain estimate. In addition, semi-qualitative information was collected concerning the quality of water (fresh, brackish, saline), and whether the extent of saltwater intrusion has increased over the period (2000-2010).

4.5. Results

4.5.1. Questionnaire responses

Contact people were identified for almost all SIDS. E-mails were sent by UNESCO-IHP to each contact. However, no acknowledgement of receipt of the emails was received from American Samoa, Commonwealth of the Northern Marianas, or Marshall Islands. Follow-up emails were then sent to identify the national experts for each SIDS. Fifteen SIDS did not provide the name of a national expert. Survey results were returned from Aruba, Jamaica, Mauritius, New Caledonia, Saint Lucia, Samoa, Sao Tome and Principe, Seychelles, and Tonga.

Contracts were issued to compile data for each of the Caribbean and the Pacific Regions. For the Caribbean Region, data were provided for five islands: Antigua, Dominica, Grenada, Saint Kitts and Nevis, and The Bahamas.

For the Pacific Region, data were provided for 17 islands: American Samoa, Cook Islands, Federated States of Micronesia, Fuji, French Polynesia, Guam, Kiribati, Marshall Islands, Nauru, Niue, Northern Marianas, Palau, Samoa, Tonga, Tuvalu, and Vanuatu. Questionnaires were completed independently and included in the package by French Polynesia, New Caledonia, and Samoa as these states had been previously contacted by UNESCO-IHP. Questionnaires from Solomon Islands and Timor Leste were submitted too late to be incorporated into this assessment.

Overall, 29 questionnaires were returned. All were incomplete, and most were missing information on each tab of the spreadsheet.

4.5.2. Current-state variables

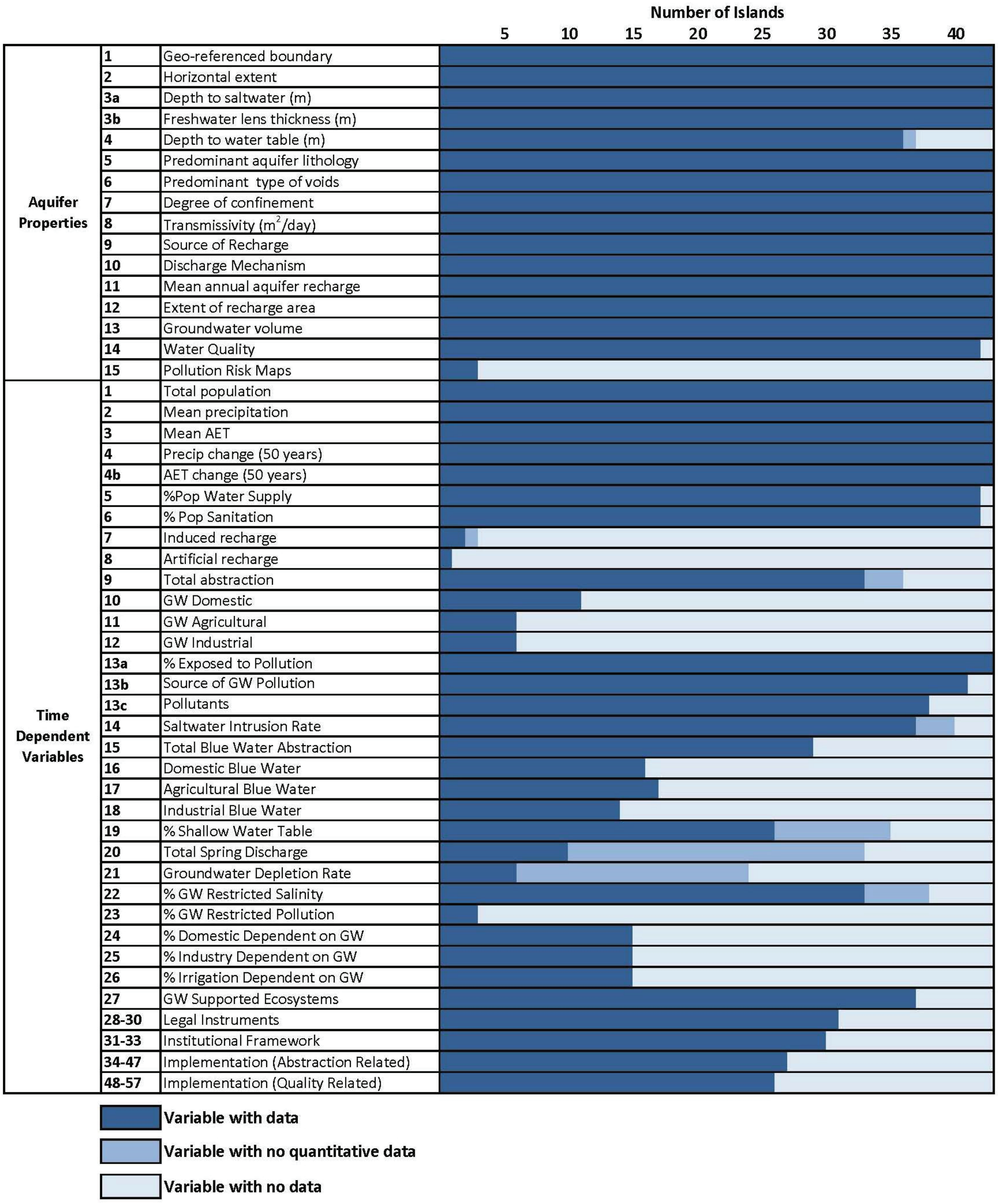
The preliminary assessment had resulted in qualitative or quantitative information for most variables (Figure 4.3. Aquifer Properties). All variables were estimated except Depth to Water Tables for The British Virgin Islands, Grenada, Saint Lucia, Saint Vincent and The Grenadines, Solomon Islands, Timor-Leste, and Trinidad and Tobago. Maps or information related to areas at risk of pollution were provided only by Jamaica, Marshall Islands and Nauru.

Confidence levels are high to moderate for most aquifer properties. Properties with low confidence overall include Depth to Saltwater near the Coast, Freshwater Aquifer Thickness, Hydraulic Conductivity, Porosity, Transmissivity, Extent of Recharge Area, and 'Groundwater Volume. These are key properties for any hydrogeological assessment. The low confidence means that these properties were estimated solely on calculations or literature values associated with rock type.

For Time-Dependent Properties, estimates of driver variables for Demography, Climate, and Water Supply and Sanitation were generally of moderate to high confidence. Only Netherlands Antilles had no data for Water Supply and Sanitation.

Variables related to Pressures were sparse. Other Sources of Groundwater Recharge (induced or artificial recharge) were generally unavailable. Data for Total Groundwater Abstraction were available for most islands, with the exception of Anguilla, British Virgin Islands, French Polynesia, Netherlands Antilles, Solomon Islands and Vanuatu. Most estimates of Total Groundwater Abstraction had high confidence. However, almost no information was available for Groundwater Abstraction According to Use (Domestic, Agricultural, and Industrial). Information for Groundwater Pollution was available for most islands, although the Percentage of Area Exposed to Pollution Sources was unavailable for most islands. With the exception of The British Virgin Islands, French Polynesia, Netherlands Antilles, Niue, and Sao Tome and Principe, information on whether or not Extent of Seawater Intrusion has increased since 2010 was available, although there was a wide range of uncertainty. Finally, about 50 per cent of the islands had information on Blue Water Extraction (Total Use and for Various Uses).

Figure 4.3. Final assessment of variables.



For State variables related to groundwater quantity, it was possible to estimate with considerable uncertainty the Percentage of the Island that has a Shallow Water Table for about 50 per cent of the islands, but limited information was available for Spring Discharge or Long-term Groundwater Depletion. For State variables related to groundwater quality, about 75 per cent of the islands had some information on Percentage of the Island where Salinity Restricts Groundwater Use, but almost no information was available for Percentage of the Island where Groundwater Pollution Restricts Groundwater Use.

Impact variables related to Services and Dependencies of Humans were estimated for about 50 per cent of the islands, and Environmental Impacts to Ecosystems' were estimated for most islands with moderate uncertainty.

For Responses variables, information on Legal Instruments, Institutional Frameworks, Implementation of Measures Related to Groundwater Abstraction, and Implementation Measures Related to Groundwater Quality were available for about 50 per cent of the islands. Islands lacking any such data include Anguilla, Barbados, British Virgin Islands, Cape Verde, Comoros, Maldives, Montserrat, Netherlands Antilles, Puerto Rico, Saint Vincent and Grenadines, Solomon Islands, Timor-Leste, Trinidad and Tobago, and US Virgin Islands. Several other islands had only partial information.

Overall, the combination of the Preliminary Assessment and the questionnaires provided a reasonably good database from which the indicators could be assessed.

4.5.3. Current-state indicators

An attempt was made to assess all indicators using the variables data. Eleven core indicators were emphasized (ten core TWAP indicators plus the Saltwater Intrusion Indicator) with varying levels of confidence, depending on the input variables. When input variables were not available for a given SIDS, the indicators were not assigned. The following summarizes the outcome for the Core Indicator assessment.

1. The indicator for Mean Annual Recharge was generally assigned moderate confidence because most of the values were derived from recharge modelling. Where higher confidence was assigned, there was general agreement between the modelling and the estimated recharge based on the questionnaire results.
2. The indicator for Annual Amount of Renewable Groundwater Resources Per Capita was assessed with low confidence for all islands. This results from the uncertainty of the recharge area and total annual recharge volume.
3. The indicator for Natural Background Groundwater Quality was assigned on the basis of the variable for the percentage of the island where salinity or other natural constituents restrict use.
4. The indicator for Human Dependence of Groundwater was estimated for only 50 per cent of the islands since it was based on the annual groundwater and blue-water abstraction volumes, the second of which was commonly not available in literature review or questionnaire results.
5. With the exception of six islands, the indicator for Groundwater Depletion could not be assessed because of lack of available data.
6. The indicator for ‘Groundwater Pollution’ was assessed for all islands, but with a high degree of uncertainty.
7. The Indicator for Saltwater Intrusion was assessed for about 75 per cent of islands. However, the indicator was based on the presence of groundwater zones contaminated by natural constituents, including salinity, and may not represent active intrusion of the saltwater interface so much as the natural groundwater quality (see Core Indicator 3). Qualitative characterization of the rate of saltwater intrusion (whether it is increasing or not) is not captured in the indicators.
8. The indicator for Population Density was assessed for all islands with generally high confidence.
9. The indicator for Groundwater Development Stress was defined for about 75 per cent of the islands, depending on whether groundwater abstraction rates were provided.
10. The indicator for Legal Framework was assessed for about 75 per cent of the islands with moderate to high confidence.
11. The indicator for Institutional Framework was assessed for about 75 per cent of the islands with moderate to high confidence.

For the non-core indicators, indicators for Aquifer Buffering Capacity, Aquifer Vulnerability to Climate Change, and Aquifer Vulnerability to Pollution were assessed for most islands, although there was a large range of uncertainty. Few indicators could be assessed for Human Dependence on Groundwater for Domestic, Agricultural and Industrial Water Supply, Ecosystem Dependence of Groundwater, and Prevalence of Springs because of limited information. Indicators were assessed for about 50 per cent of islands for Control of Groundwater Abstraction and Groundwater Quality Protection.

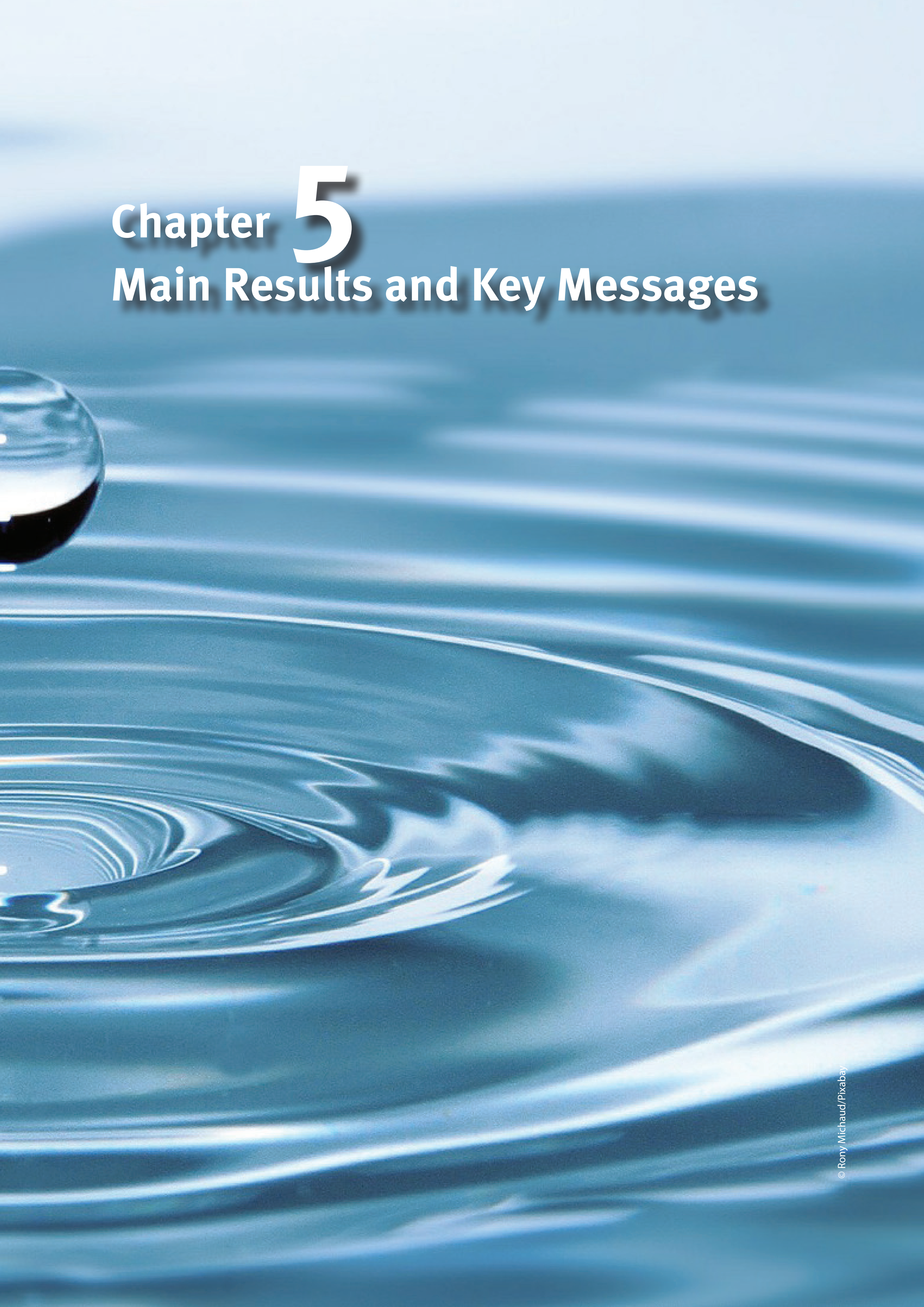
References

Allen, D.M., Foster, S., Gurdak, J., Holding, S., Hsieh, A., Klassen, J., Larocque, I., Taniguchi, M., and Van Pelt, S. (2015). Assessment of SIDS groundwater systems. Transboundary water Assessment Programme (TWAP), final report. UNESCO-IHP, Paris. Available at: http://twap.isarm.org/

Part D. Final remarks

Chapter 5

Main Results and Key Messages



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Chapter Citation: Merla, A., Nijsten, G.J., Aureli, A. (2016). Chapter 5: Main results and key messages. In UNESCO-IHP and UNEP (2016). Transboundary Aquifers and Groundwater Systems of Small Island Developing States Status and Trends. United Nations Environment Programme, Nairobi, pp. 117-119.

5. Main Results and Key Messages

5.1. Transboundary aquifers

Worldwide, the majority of transboundary aquifers with surface expression greater than 5 000 km^2 are located outside regions highly affected by groundwater development stress, and show very low depletion rates of less than 2 mm/yr in most regions of the world. Human dependence on transboundary groundwater is still generally low to very low in 193 out of the total 258 TBA national segments analysed.

It is therefore possible to conclude that groundwater resources are still potentially available for development in transboundary groundwater basins and aquifer systems. When considering that this assessment, based mainly on modelling, has, by necessity, not taken into consideration the vertical dimension of aquifers, that is the existence and thickness of multi-layered systems and deep-seated aquifers, the quantity of these still unexploited reserves becomes very large.

The high residence times of groundwater, which has been found by this assessment to be more than 100 years and up to more than 1 000 years for a number of TBAs in the Sahel and Saharan Africa, Central and South Asia, adds value to these transboundary resources because of their capacity to mitigate the effects of prolonged climatic extremes.

The number of TBA hotspots resulting from combinations of high human dependence, low renewable groundwater per capita, and high extraction/recharge ratios, is rather limited. Under the worst-case climate and irrigation scenario, the national segments of transboundary aquifers in the high risk and very high risk hotspot categories are expected to increase between now and 2030 and/or 2050 from 20 to 58. New hotspots, mainly driven by population pressures, are projected to develop mainly in Sub-Saharan Africa, China and Mexico. The highest future groundwater development stress values as well as the largest increases of groundwater development stress of up to 40 percentage points are projected for TBA country segments in Botswana, the Middle East and North Africa region, South Asia, Uzbekistan, and Yucatán. For the future, eight new country segments were identified as potential hotspots of "groundwater crowding" (low per-capita groundwater resources and a medium to very high dependence on groundwater), all of them in West or East Africa.

The assessment failed to produce enough information on anthropogenic pollution in TBAs to enable conclusions to be drawn at the global level. However it highlighted that all TBAs highly impacted by irrigation return flows in densely populated areas with low to medium natural recharge, as is the case in the Nubian, Indus, Pre-Caspian transboundary aquifers, are characterized by very low background groundwater quality.

The findings of TWAP Groundwater highlight the still largely untapped potentialities of transboundary groundwater systems and delineate main areas at higher risk of groundwater stress and degradation. The assessment has enabled the identification of critical factors that may prevent, or hinder our ability to exploit these critically important shared resources sustainably.

The lack of adequate groundwater governance at the global, regional and local levels "…hinders the achievement of groundwater resources management goals such as resource sustainability, water security, economic development, equitable access to benefits from water and conservation of ecosystems." This authoritative statement is even more valid when applied to transboundary groundwaters. Indeed the assessment has confirmed that governance and institutional frameworks for TBAs are totally absent, with the notable exception of five cases, three of which are in Africa.

The assessment has also provided evidence of an alarming lack of knowledge and modern data on groundwater in general, and TBAs in particular. This assessment would not have been possible without the help of modelling. The information received through the widely distributed questionnaires, notwithstanding the highly-appreciated efforts of hundreds of national and regional experts, undoubtedly reflects the lack of quantitative, modern standardized data on many key groundwater parameters, and the generalized limited knowledge of the subsurface and its water resources. The failure to provide even minimal information on groundwater dependent ecosystems has been more surprising.

Moreover, issues of sovereignty, the widely perceived need for official endorsement of technical data, and the sensitivity and growingly strategic nature of transboundary water resources, are among the factors that have precluded a greater, more proactive response to questionnaires. The limited financial resources have also played a constraining role.

Modelling has enabled estimates to be made of all hydrogeological and socio-economic indicators for all major TBAs and their national segments, and the development of future scenarios for 2030 and 2050. For the environmental and governance indicators, the only sources of information were the questionnaires, and values for these indicators are therefore available for only a fraction of all TBAs. The use of models, increasingly indispensable with their ability to fill data gaps, simulate, extrapolate and forecast, however has limitations, which are particularly obvious in the case of aquifers. Global models are constrained by lack of ground data, and by their inability to consider the three-dimensional nature of aquifers and the complexities of subsurface water flow and recharge patterns. Their outputs must be considered with caution.

Despite all this, TWAP Groundwater has been able to establish the first Global Inventory of Transboundary Aquifers, contained in the publicly-open TWAP Groundwater Information Management System, and to produce standardized data collection and assessment methodologies, which are now being already applied a the single TBA scale in Sub-Saharan Africa, Central Asia, and Central America. These are cornerstone achievements and resources now available to all.

Finally, having reached the end of this large cooperative effort, it can be concluded that the current state and projected trends of TBAs emerging from TWAP Groundwater will enable some, albeit limited responses to the basic TWAP questions highlighted in the Section 1.1 of this final report.

Useful elements have been gathered to help identify areas where transboundary groundwater use is being progressively constrained by degradation of background quality, development stress, and lack of governance frameworks. High-risk areas of future groundwater stress have been identified by considering worse-case climatic and agricultural scenarios. The role of transboundary aquifers and their still largely untapped groundwater resources in preventing, buffering or mitigating impacts of global changes on human livelihoods and the environment has been highlighted.

Recommendations for actions are implicit in these final remarks. Modern data, and governance frameworks, are the highest priorities in the fight against the looming threats to global water security.

5.2. Small Island Developing States

The situation that emerges from the analysis of the groundwater resources of SIDS calls for immediate attention. In the absence of coordinated, sustained remedial national and international action, the inhabitants of low-lying islands in the Pacific, highly dependent on scarce, polluted and increasingly saline groundwater resources, and impacted by climatic variability and change, are facing dramatic choices. In many other islands, degradation of groundwater quality and growing demands are posing short-medium term threats to human health, and impairing the provision of ecosystem services of great economic importance .

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Technical Appendices

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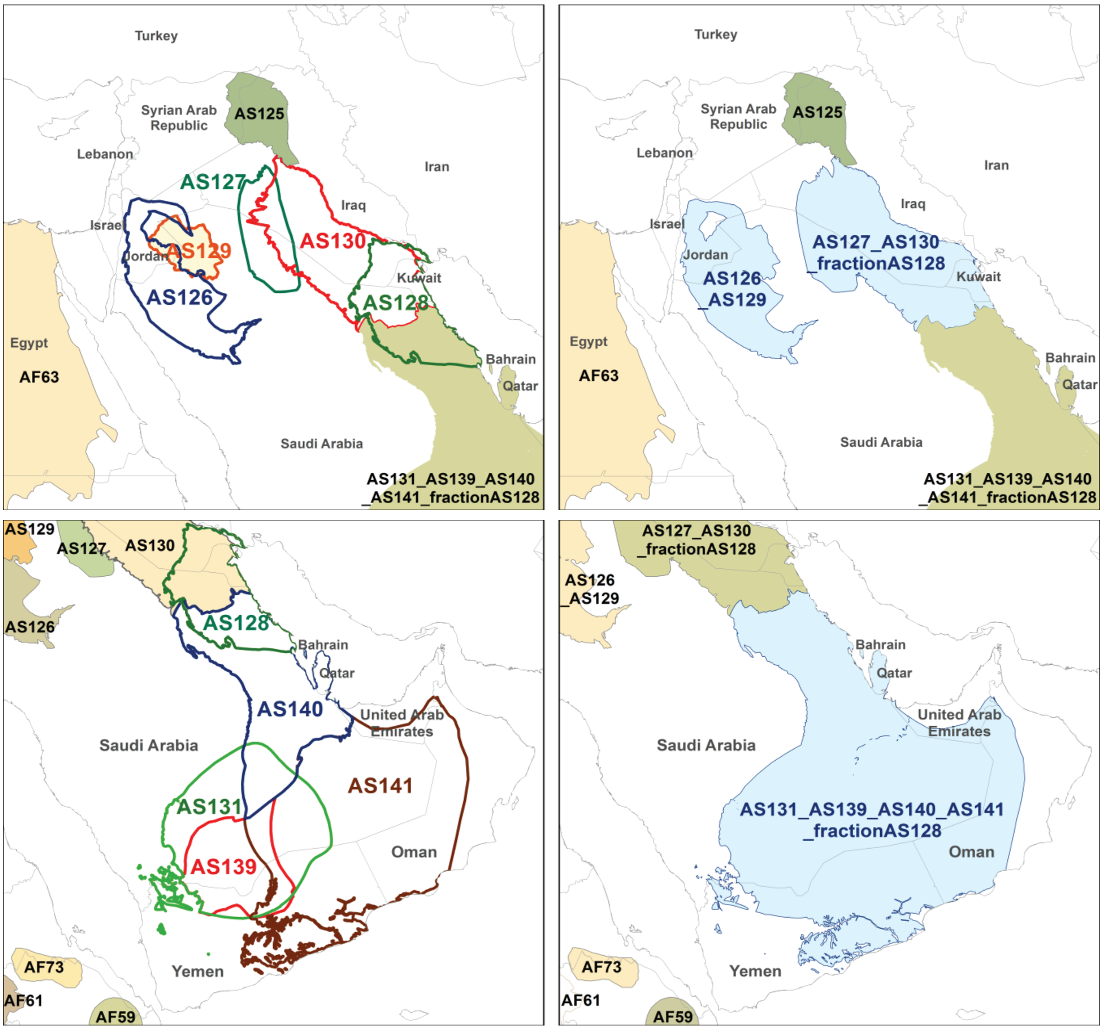
Contents

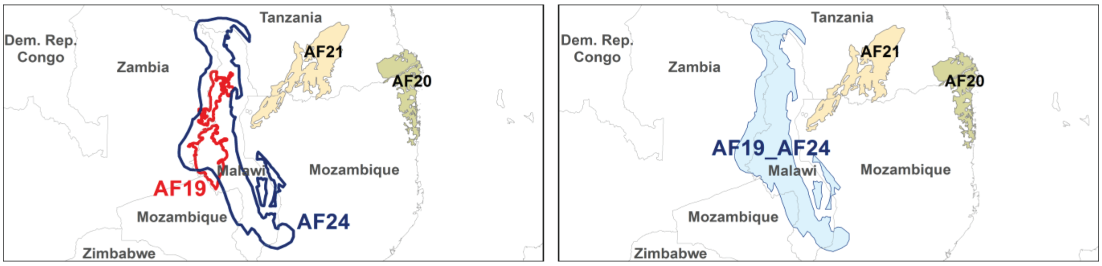
Appendix 1 – WaterGAP – Documentation of merged transboundary aquifers

In the following figures, TBAs merged due to large overlaps are documented. Original TBA boundaries and codes are depicted on the left, boundaries of the respective merged TBAs and the new codes (combination of the original codes) are shown on the right.

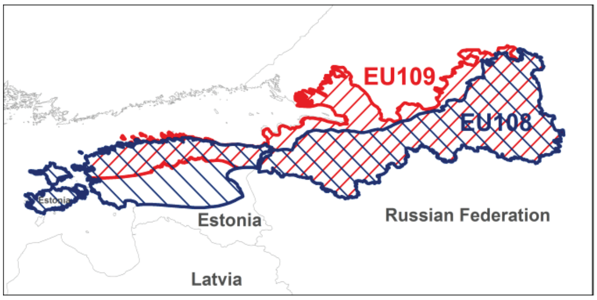
Arabian Peninsula:



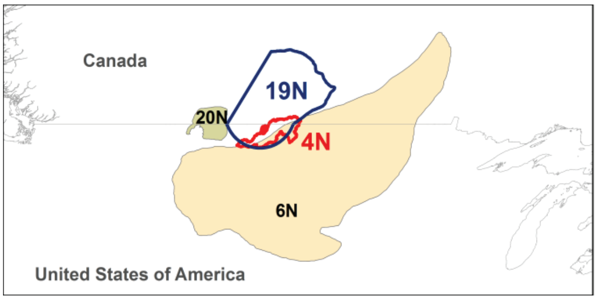
Africa:

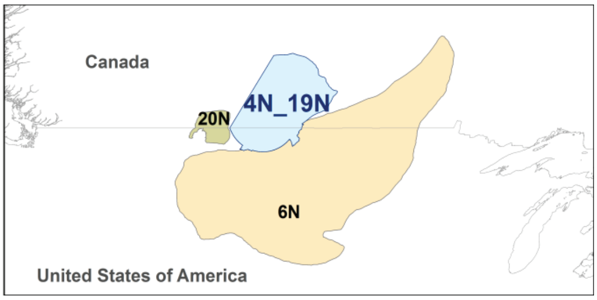


Europe:

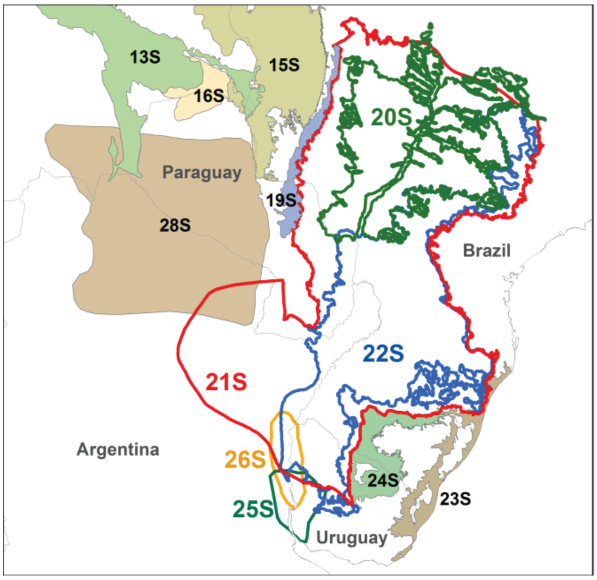


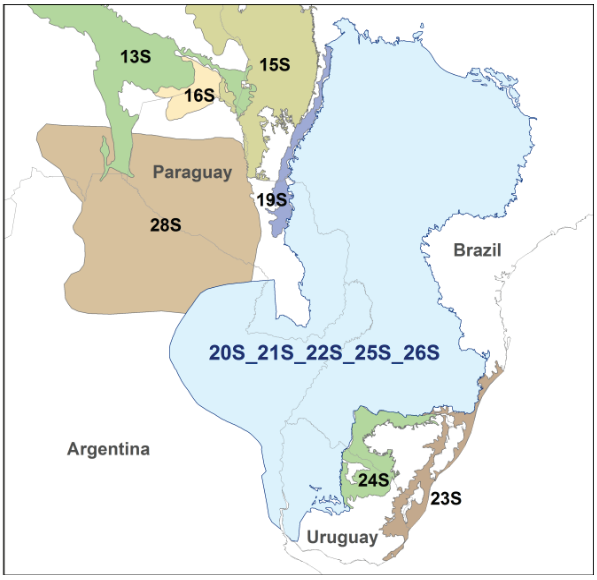
North America:

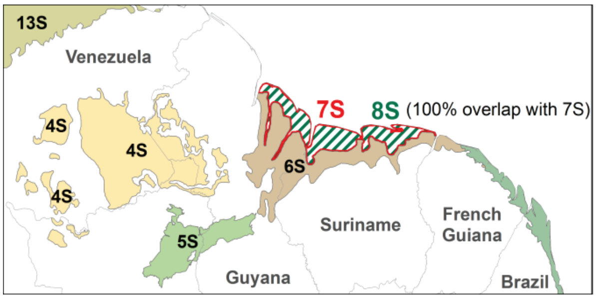


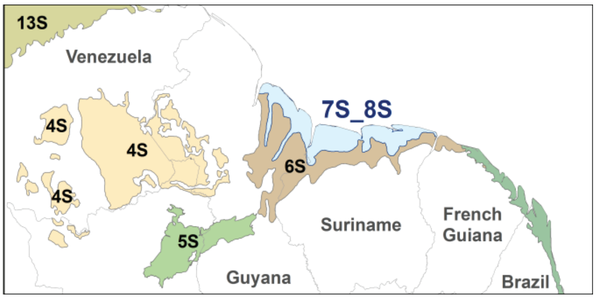


South America:









Appendix 2 – Transboundary Aquifer Briefs: examples

Appendix 2-1: 13S - Amazonas

Appendix 2-2: AF52 - Lake Chad

Appendix 2-3: AF14 - Nata Karoo Sub-Basin - Caprivi Aquifer

Appendix 2-4: EU283 - Belgian-Dutch-German Lowland Aquifer System

Appendix 2-5: AS126 - Saq-Ram Aquifer System (West)

Appendix 2-6: AS74 - Tacheng Basin / Alakol

These Transboundary Aquifers information sheets have been produced as part of the Groundwater Component of the GEF Transboundary Water Assessment Programme (GEF TWAP). **GEF TWAP** is the first truly global comparative assessment of transboundary groundwater, lakes, rivers, large marine ecosystems and the open ocean. More information on TWAP can be found on: www.geftwap.org . **The Groundwater component** of TWAP carried out a global comparison of 199 transboundary aquifers and the groundwater systems of 42 Small Island Developing States.

The data used to compile this transboundary aquifer information sheet has been made available by national and regional experts from countries involved in the TWAP Groundwater project. For aquifers larger than 20 000 km^2 and which are not overlapping, additional data are available from modelling done by the Goethe University Frankfurt (Germany) as part of TWAP Groundwater. All data were compiled by UNESCO-IHP and the International Groundwater Resources Assessment Centre (IGRAC – UNESCO Category II Institute). Values given in the fact-sheet represent an approximate guide only and should not replace data obtained from recent local assessments. The editors of this information sheet are not responsible for the quality of the data.

For more information on TWAP Groundwater and for more data, please have a look at the TWAP Groundwater Information Management System which is accessible via www.twap.isarm.org or www.un-igrac.org.

References

Population: Population has been calculated based on the aquifer map and grid information on population. Source population data: Center for International Earth Science Information Network - CIESIN - Columbia University, United Nations Food and Agriculture Programme - FAO, and Centro Internacional de Agricultura Tropical - CIAT. 2005. Gridded Population of the World, Version 3 (GPWv3): Population Count Grid, Future Estimates. Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC). http://dx.doi.org/10.7927/H42B8VZZ. Accessed Jan 2015.

Rainfall: Average rainfall per TBA has been calculated based on the aquifer map and grid data for precipitation. Source precipitation data: Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones and A. Jarvis, 2005. Very high resolution interpolated climate surfaces for global land areas. International Journal of Climatology 25: 1965-1978. Grid data download from www.worldclim.org (2015): Data for current conditions (~1950-2000), ESRI grids, 30 arc seconds, Precipitation.

Climate: Climate indicates the major climate zone which occurs in the aquifer area. If more than 1 climate zone is present the zone with the largest surface area was selected. Source climate data: ArcGIS Online (2015), Simplified World Climate zones. Owner: Mapping Our World GIS Education. Original map: National Geographic World Atlas for Young Explorers (1998).

All other data: TWAP Groundwater.

Transboundary Aquifer Information Sheet

13S - Amazonas

Geography

Total area TBA (km^2): 3 600 000

No. countries sharing: 7

Countries sharing: Argentina, Bolivia, Brazil, Colombia, Ecuador, Peru, Venezuela

Population: 18 000 000

Climate zone: Tropical Wet

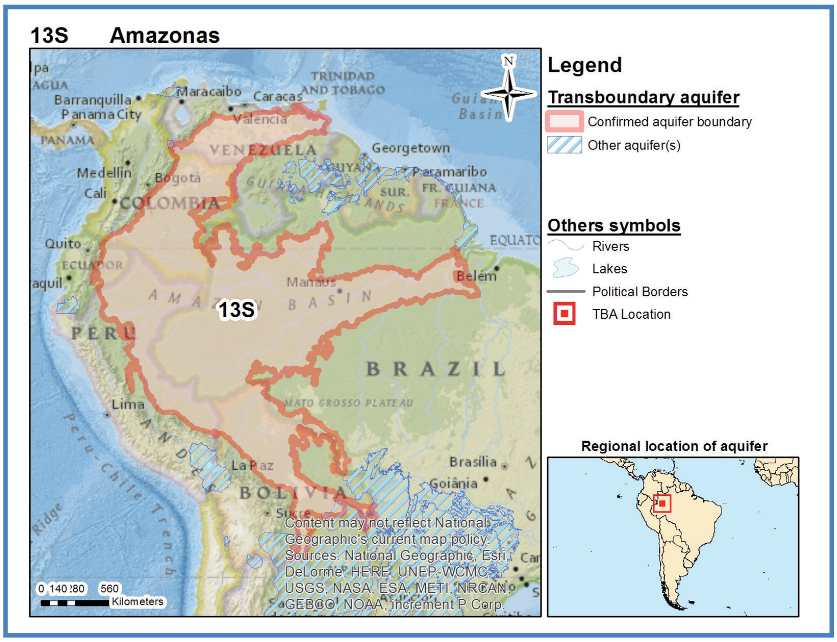
Rainfall (mm/yr): 2 300

Hydrogeology

Aquifer type: Multiple layers hydraulically connected

Degree of confinement: Mostly unconfined, but in some parts confined

Main lithology: Sedimentary rocks - Sandstone



No Cross-section provided

Map and cross-section are only provided for illustrative purposes. Dimensions are only approximate.

Transboundary Aquifer Information Sheet

13S - Amazonas

	Recharge (mm/y) (1)	Renewable groundwater per capita (m^3/y/capita)	Natural background groundwater quality (%) (2)	Human dependency on groundwater (%)	Groundwater depletion (mm/y)	Groundwater pollution (%) (3)	Population density (Persons/km2)	Groundwater development stress (%) (4)	Transboundary legal framework (Scores) (5)	Transboundary institutional framework (Scores) (6)
Argentina							11			
Bolivia							6			
Brazil							3		D	C
Colombia							5		D	B
Ecuador							7			
Paraguay							3			
Peru			70				3			D
Venezuela	32	1 800	90		0		18	<5	B	D
TBA level							**5**			

(1) Recharge: This is the long term average recharge (in m^3/yr) divided by the surface area (m^2) of the complete country segment of the aquifer (i.e. not only the recharge area).

(2) Natural background groundwater quality: Estimate of percentage of surface area of aquifer where the natural groundwater quality satisfies local drinking water standards.

(3) Groundwater pollution: A. No pollution has been identified; B. Some pollution has been identified; Positive number: Significant pollution has been identified (% of surface area of aquifer).

(4) Groundwater development stress: Annual groundwater abstraction divided by recharge.

(5) Legal framework: A. Agreement with full scope for TBA management signed by all parties; B. Agreement with limited scope for TBA management signed by all parties; C. Agreement under preparation or available as an unsigned draft; D. No agreement exists, nor under preparation; E. Legal Framework differs between Aquifer States (see data at National level).

(6) Institutional Framework: A. Dedicated transboundary institution fully operational; B. Dedicated transboundary institution in place, but not fully operational; C. National/Domestic institution fully operational; D. National/Domestic institution in place, but not fully operational; E. No institution exists for TBA management; F. Institutional Framework differs between Aquifer States (see data at National level).

X A value was provided in the questionnaire, but it was considered un-realistic and therefore removed from the table.

TWAP Groundwater Indicators from WaterGAP model

	Recharge, incl. recharge from irrigation (mm/yr)	Renewable groundwater per capita			Human dependency on groundwater (%)	Human dependency on groundwater for domestic water supply (%)	Human dependency on groundwater for irrigation (%)	Human dependency on groundwater for industrial water use(%)
		Current state (m^3/y/capita)	Projection 2030 (% change to current state)	Projection 2050 (% change to current state)				
Argentina	49	4900	-18	-39	21	11	4	38
Bolivia	260	46 000	-35	-52	22	57	4	2
Brazil	540	180 000	-17	-21	11	32	23	3
Colombia	640	120 000	-18	-26	17	22	3	8
Ecuador	510	77 000	-20	-28	6	32	5	0
Paraguay	44	21 000	-28	-48	7	36	4	42
Peru	520	160 000	-22	-31	18	27	18	9
Venezuela	190	9400	-31	-45	8	21	1	1
TBA level	**490**	**92 000**	**-23**	**-33**	**11**	**26**	**1**	**3**

Transboundary Aquifer Information Sheet

13S - Amazonas

	Groundwater depletion (mm/y)	Population density			Groundwater development stress		
		Current state (Persons/km2)	Projection 2030 (% change to current state)	Projection 2050 (% change to current state)	Current state (%)	Projection 2030 (% point change to current state)	Projection 2050 (% point change to current state)
Argentina	0	10	19	32	1	1	2
Bolivia	-1	6	40	80	<1	0	0
Brazil	-2	3	16	22	<1	0	0
Colombia	0	5	23	36	<1	0	0
Ecuador	-1	7	27	43	<1	0	0
Paraguay	0	2	39	77	<1	0	0
Peru	0	3	26	41	<1	0	0
Venezuela	3	20	32	52	<1	0	0
TBA level	**-1**	**5**	**26**	**44**	<1	0	0

Key parameters table from Global Inventory

	Distance from ground surface to groundwater table (m)	Depth to top of aquifer formation (m)	Full vertical thickness of the aquifer (system)* (m)	Degree of confinement	Predominant aquifer lithology	Primary Porosity	Secondary Porosity	Transmissivity (m^2/d)
Argentina								
Bolivia								
Brazil			400	Aquifer mostly unconfined, but some parts confined	Sedimentary rocks - Sandstone	Low primary porosity intergranular porosity	Secondary porosity: Dissolution	
Colombia								
Ecuador								
Paraguay								
Peru	6**	20**	25	Aquifer mostly unconfined, but some parts confined	Sedimentary rocks - Sandstone	Very high primary porosity gravels/ pebbles	Secondary porosity: Fractures	
Venezuela	6**	40**	34	Aquifer mostly unconfined, but some parts confined	Sediment Sand	High primary porosity fine/ medium sedimentary deposits	Secondary porosity: Dissolution	500
TBA level								

* Including aquitards/aquicludes

** These values would need revision as a groundwater table higher than depth to top of the aquifer is un-realistic for an unconfined aquifer.

X A value was provided in the questionnaire, but it was considered un-realistic and therefore removed from the table.

Transboundary Aquifer Information Sheet

13S - Amazonas

Aquifer description

Aquifer geometry

Only three of the six TBA countries have provided information for this large aquifer system. It is a multiple-layered hydraulically connected system. The average depth to the water table is 6m in both Brazil and Venezuela. The average depth to the top of the aquifer is 20m and 40m in Brazil and Venezuela respectively. The thickness of the aquifer system varies between 25m and 400m (greatest thickness in Brazil). The aquifer is mostly unconfined, but in some parts confined.

Hydrogeological aspects

The Regional Report sums up the aquifer type as Sedimentary: unconsolidated and consolidated sandstones and clays. In the database for Brazil and Peru describe the predominant aquifer lithology as sedimentary rocks: shale and for Venezuela as sediment: sand. The shale lithology appears inconsistent with the porosity information that is provided, and should be reviewed. Venezuela reports an average transmissivity of 500m²/day (variation: 200-1 500m²/day). The total groundwater volume in Venezuela is 80km^3. The average annual recharge into the system in Venezuela is 10 000 million m^3/annum.

Links with other water systems

Recharge to the system is from precipitation over the aquifer area (see appendix 1), discharge is through river base flow and outflow into lakes (in the case of Venezuela) (see appendix 2).

Environmental aspects

Around 10% of the natural groundwater in Venezuela and 30% in Peru are unsuitable for human consumption but the main cause is not recorded. Venezuela reports that this is only within the superficial layers. Some anthropogenic pollution has been identified in Brazil, Peru, and Venezuela where it is only over the superficial layers. It is due to diverse causes including urban, industrial, agricultural and mining activities. The natural water quality is good, but the aquifer has high vulnerability in several points where the water table is close to the surface. In Venezuela 40% of the aquifer has shallow groundwater whereas this increases to 70% in Peru. Only Venezuela reports on the aquifer area covered with groundwater dependent ecosystems, very high at 70%.

Socio-economic aspects

The exploitation of the aquifer system varies widely between countries. Indications are that, in general, the level of use of the aquifer system is still moderate and no problems have been detected in this regard. In general the largest use is for public supply and domestic use, except in Venezuela where the highest use is for irrigation (70%). This country reports an average groundwater abstraction of 23 million m^3/annum.

Legal and Institutional aspects

There is no common reporting under this point. Venezuela reports on a ratified Multi-lateral Agreement with limited scope. The River Basin agreement (Tratado de Cooperación Amazónica - Bolivia, Brasil, Colombia, Ecuador, Guyana, Perú, Suriname and Venezuela) can provide the basis for future agreements for joint management of groundwater.

Emerging issues

The high vulnerability of the shallow aquifer system to pollution appears as an emerging issue. Closer attention also needs to be paid to the conservation of groundwater-dependent ecosystems. Reporting has been poor in this important international system and this needs to be addressed in all countries.

Transboundary Aquifer Information Sheet

13S - Amazonas

Contributors to Global Inventory

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Considerations and recommendations

Most data in the tables and text above have been provided by national and regional experts (listed above) or have been derived from the global WaterGAP model. See colophon for more information, including references to data from other sources.

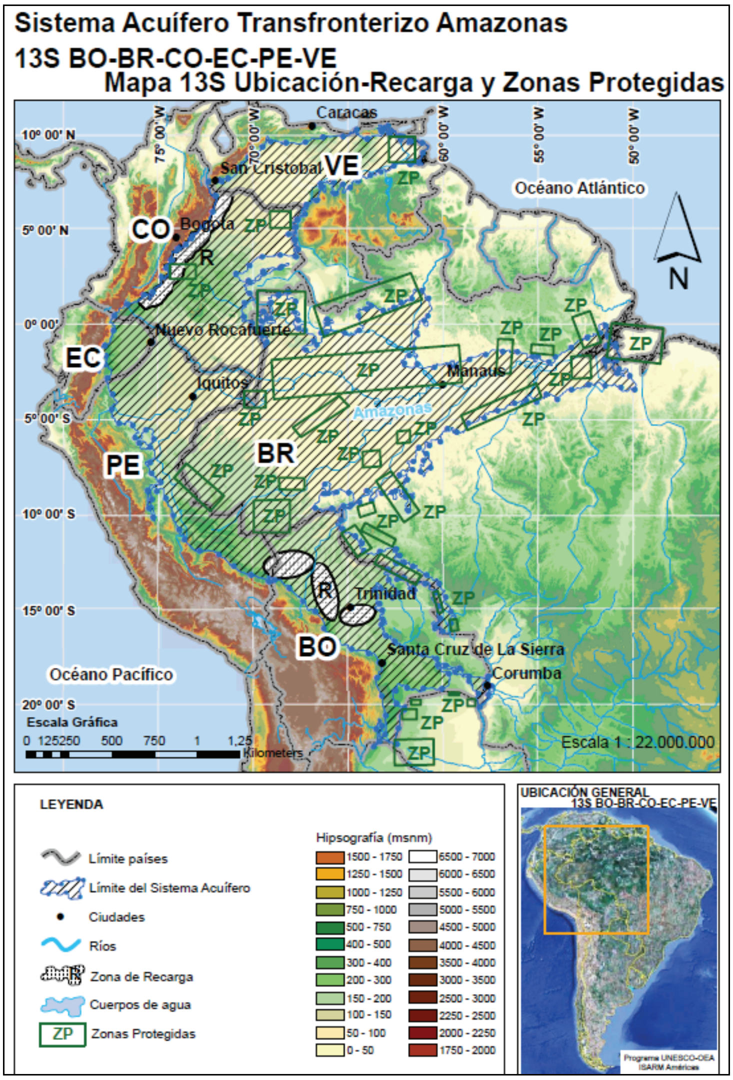
Only three of the six TBA countries have provided information. This information was also inconsistent and did not allow for an adequate description of this large aquifer system. Only Venezuela provided some quantitative information that allowed calculation of indicators.

Data gaps and also differences between data from national experts (Global Inventory) and data derived from WaterGAP highlight the need for further research on transboundary aquifers.

Transboundary Aquifer Information Sheet

13S - Amazonas

Appendix 1:



Location of recharge and protection zones

Transboundary Aquifer Information Sheet

13S - Amazonas

Appendix 2:

Showing an area with the main Groundwater Flow directions

Transboundary Aquifer Information Sheet

AF52 - Lake Chad Basin

Geography

Total area TBA (km^2): 2 000 000

No. countries sharing: 7

Countries sharing: Algeria, Cameroon, Central Africa Republic, Chad, Libya, Niger, Nigeria

Population: 40 000 000

Climate Zone: Arid

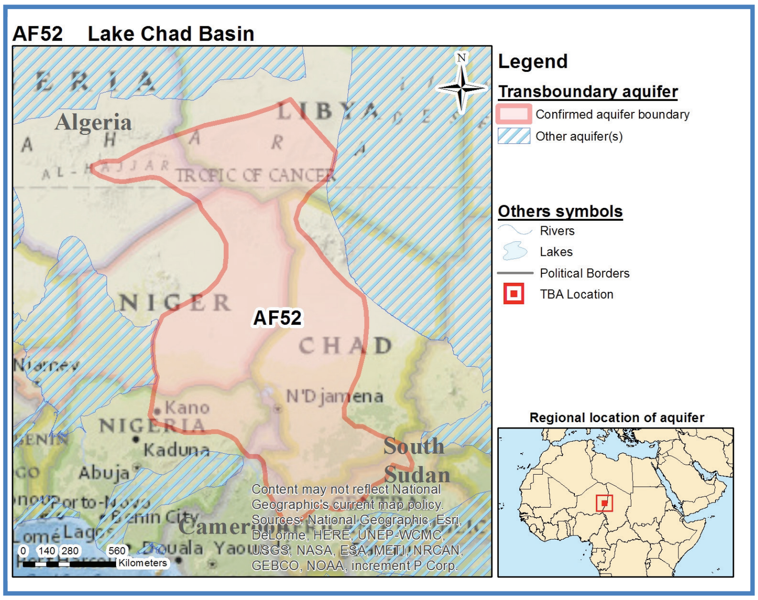
Rainfall (mm/yr): 310

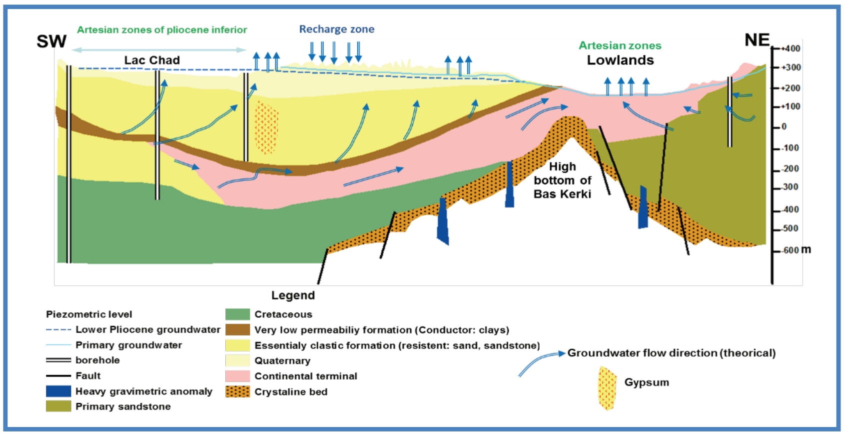
Hydrogeology

Aquifer type: Multiple layers hydraulically connected

Degree of confinement: Mostly unconfined but some parts confined

Main Lithology: Sediment - Sand and Limestones





Cross section along Maiduguri to the SW and Faya Largeau to the NE of the Lake Chad Basin (after Schneider & Wolff, 1992 modified)

Map and cross-section are only provided for illustrative purposes. Dimensions are only approximate

Transboundary Aquifer Information Sheet

AF52 - Lake Chad Basin

TWAP Groundwater Indicators from Global Inventory

	Recharge (mm/y) (1)	Renewable groundwater per capita (m^3/y/capita)	Natural background groundwater quality (%) (2)	Human dependency on groundwater (%)	Groundwater depletion (mm/y)	Groundwater pollution (%) (3)	Population density (Persons/km2)	Groundwater development stress (%) (4)	Transboundary legal framework (Scores) (5)	Transboundary institutional framework (Scores) (6)
Algeria							0			
Cameroon							70			
Central African Republic	X	<1				B	8	> 1 000	C	C
Chad	<1	<1	70			B	13	>1 000		
Libya							1		A	D
Niger							6			
Nigeria							130			A
TBA level										

(1) Recharge: This is the long term average recharge (in m^3/yr) divided by the surface area (m^2) of the complete country segment of the aquifer (i.e. not only the recharge area).

(2) Natural background groundwater quality: Estimate of percentage of surface area of aquifer where the natural groundwater quality satisfies local drinking water standards.

(3) Groundwater pollution: A. No pollution has been identified; B. Some pollution has been identified; Positive number: Significant pollution has been identified (% of surface area of aquifer).

(4) Groundwater development stress: Annual groundwater abstraction divided by recharge.

(5) Legal framework: A. Agreement with full scope for TBA management signed by all parties; B. Agreement with limited scope for TBA management signed by all parties; C. Agreement under preparation or available as an unsigned draft; D. No agreement exists, nor under preparation; E. Legal Framework differs between Aquifer States (see data at National level).

(6) Institutional Framework: A. Dedicated transboundary institution fully operational; B. Dedicated transboundary institution in place, but not fully operational; C. National/Domestic institution fully operational; D. National/Domestic institution in place, but not fully operational; E. No institution exists for TBA management; F. Institutional Framework differs between Aquifer States (see data at National level).

X A value was provided in the questionnaire, but it was considered un-realistic and therefore removed from the table.

Groundwater TWAP TRANSBOUNDARY WATERS ASSESSMENT PROGRAMME

Transboundary Aquifer Information Sheet

AF52 - Lake Chad Basin

TWAP Groundwater Indicators from WaterGAP model

	Recharge, incl. recharge from irrigation (mm/yr)	Renewable groundwater per capita			Human dependency on groundwater (%)	Human dependency on groundwater for domestic water supply (%)	Human dependency on groundwater for irrigation (%)	Human dependency on groundwater for industrial water use (%)
		Current state (m^3/y/capita)	Projection 2030 (% change to current state)	Projection 2050 (% change to current state)				
Algeria	<1	1000	40	-7	68	22	99	<1
Cameroon	320	4500	-30	-52	29	59	6	29
Central African Republic	160	19000	-32	-52	55	57	12	27
Chad	200	15000	-29	-54	27	52	12	1
Libya	<1	670	-12	-26	91	69	100	<1
Niger	10	1500	-15	-48	42	87	9	67
Nigeria	230	1700	-25	-52	42	89	18	84
TBA level	**110**	**5300**	**-29**	**-55**	**48**	**76**	**36**	**56**

	Groundwater depletion (mm/y)	Population density			Groundwater development stress		
		Current state (Persons/km2)	Projection 2030 (% change to current state)	Projection 2050 (% change to current state)	Current state (%)	Projection 2030 (% point change to current state)	Projection 2050 (% point change to current state)
Algeria	0	<1	33	56	19	9	13
Cameroon	0	72	49	100	<1	0	1
Central African Republic	1	8	47	99	<1	0	0
Chad	1	13	63	140	<1	0	0
Libya	1	1	26	49	350	-17	-8
Niger	0	7	92	240	1	1	8
Nigeria	1	130	62	150	2	3	14
TBA level	**1**	**21**	**63**	**150**	**1**	**1**	**3**

UNEP gef United Nations Educational, Scientific and Cultural Organization · International Hydrological Programme igrac International Groundwater Resources Assessment Centre

Transboundary Aquifer Information Sheet

AF52 - Lake Chad Basin

Key parameters table from Global Inventory

	Distance from ground surface to groundwater table (m)	Depth to top of aquifer formation (m)	Full vertical thickness of the aquifer (system)* (m)	Degree of confinement	Predominant aquifer lithology	Predominant type of porosity (or voids)	Secondary Porosity	Transmissivity (m^2/d)
Algeria								
Cameroon	30	40						
Central African Republic	60**	100**	300	Aquifer mostly unconfined, but some parts confined	Sediment -Sand		Secondary porosity: Fractures	
Chad	33	7	530	Aquifer mostly unconfined, but some parts confined				X
Libya			700	Aquifer mostly confined, but some parts unconfined	Sediment - Sand	High primary porosity fine/medium sedimentary deposits	Secondary porosity: Dissolution	
Nigeria				Aquifer mostly unconfined, but some parts confined	Sediment -Sand	High primary porosity fine/ medium sedimentary deposits	Secondary porosity: Weathering	
Niger								
TBA level								

* Including aquitards/aquicludes

** These values would need revision as a groundwater table higher than depth to top of the aquifer is un-realistic for an unconfined aquifer.

X A value was provided in the questionnaire, but it was considered un-realistic and therefore removed from the table.

Aquifer description

Aquifer geometry

Although it is mainly a multi three-layered hydraulically connected system, it reduces to two layers in Libya, and is single-layered in Nigeria. The aquifers are generally unconfined with parts being confined. However in Libya the aquifers are generally confined with some unconfined parts. The average water level varies from 30 m (Cameroon) to 60 m (Central African Republic). The average depth to the top of the aquifer varies from 7 m (Chad) to 100 m (Central African Republic). The average full vertical thickness of the aquifer system varies from 300 m (Central African Republic) to 700 m (Libya).

Hydrogeological aspects

The predominant aquifer lithology consists of sediments – sands, and sandstones, that are calcareous in places (dissolution was noted within Libya as a secondary porosity). These generally have a high primary porosity with secondary porosity that is due either to weathering, fractures, and/ or dissolution (Central African Republic, Libya, Nigeria). Furthermore it is characterised by a high

AF52 - Lake Chad Basin

horizontal and a high to low vertical connectivity (Central African Republic, Libya, Nigeria). The total groundwater volume in two of the countries is 5 059 km^3 (Chad, Libya). There is a seasonal difference in recharge events (Central African Republic, Libya, Nigeria). The average annual recharge in part of the aquifer is 100 million m3/annum (Central African Republic). The amounts for the extreme recharge events have not been recorded. The recharge area in part of the aquifer covers an area of 40 000km^2 (Central African Republic, Nigeria). The total percentage of groundwater recharge that is due to natural recharge varies from 32 % (Nigeria) to 100 % (Cameroon).

Linkages with other water systems

The predominant source of recharge is through infiltration from a surface water body (Chad), and from precipitation on the aquifer area (Cameroon). The natural discharge mechanism is through evapotranspiration (Chad, Cameroon, Niger), through outflow into lakes (Nigeria), and through discharge from springs (Libya where an amount of 1.8 million m3/yr was measured).

Environmental aspects

The percentage of natural groundwater quality that is not suitable for human consumption has only been quantified in Chad where this comprises 30% of the aquifer. Elevated amounts of natural salinity within the superficial layers have been reported (Chad, Libya) and this is over a significant part of the aquifer (Nigeria), which also shows elevated amounts of fluoride and other heavy metals. High amounts of fluoride and other undisclosed negative elements have been reported in the superficial layers (Cameroon). Elevated amounts of nitrates, iron, and manganese occur (Central African Republic), but the extent was not specified. Anthropogenic groundwater pollution has been reported in (Cameroon, Central African Republic, Chad, Nigeria). This has been quantified between <5% (Central African Republic) to 30% (Chad) of the aquifer area, mainly in the superficial layers. A significant part of the aquifer has been polluted in Nigeria but the data are not available to determine the percentage of the aquifer area that has been affected. Data are also not available on shallow groundwater and groundwater-dependent ecosystems over the aquifer area.

Socio-economic aspects

Groundwater abstraction for 2010 from the aquifer amounted to 0.28 million m3 (Chad) and 0.15 million m3 (Central African Republic), totalling 0.43 million m3. This information was based on data from a database and/ or a dedicated study. Data were not available on the total amount of fresh water abstraction over the entire aquifer area.

Legal and Institutional aspects

The information on Agreements is not consistent. Libya reports that a signed Agreement with full scope exists, and the Central African Republic reports an Agreement with limited scope that has been prepared. A Dedicated Transboundary Institution is in place, and is fully operational (Nigeria). National Institutes exist with a full mandate and capacity (Central African Republic, Nigeria), and with a limited mandate and capacity (Libya).

Priority Issues

With regard to water quality, about 30% of the aquifer area in Chad is unsuitable for human consumption because of the natural conditions and pollution, whereas in some of the other countries this has not been quantified. This is also an important aspect that should receive more attention at a TBA level. The current status of the signed and limited scope Agreements must be reviewed with the purpose of broadening these for application for all of the Basin States.

AF52 - Lake Chad Basin

Contributors to Global Inventory

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Considerations and recommendations

Most data in the tables and text above have been provided by national and regional experts (listed above) or have been derived from the global WaterGAP model. See colophon for more information, including references to data from other sources.

Five of the seven TBA countries have contributed to the information. Information was adequate to describe the aquifer in general terms. Some quantitative information was provided but this was insufficient to calculate most of the indicators. The transmissivity values that were provided appear to be unrealistic and these values should be reviewed. The issue of the total amount of groundwater abstraction from the aquifer, thought to be a significant amount, must be re-assessed.

Data gaps and also differences between data from national experts (Global Inventory) and data derived from WaterGAP highlight the need for further research on transboundary aquifers.

Transboundary Aquifer Information Sheet

AF14 - Nata Karoo Sub-Basin - Caprivi Aquifer (Namibia)

Geography

Total area TBA (km^2): 80 000

No. countries sharing: 5

Countries sharing: Angola, Botswana, Namibia, Zambia, Zimbabwe

Population: 260 000

Climate Zone: Tropical Dry

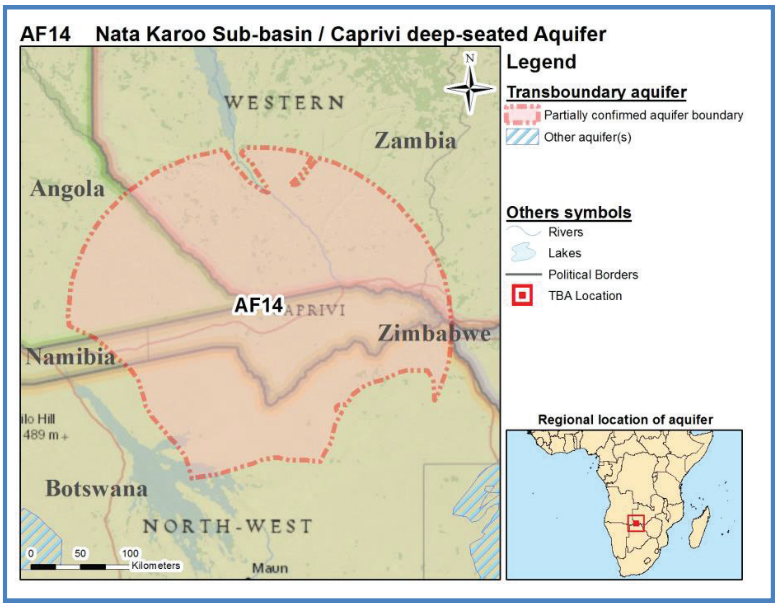
Rainfall (mm/yr): 630

Hydrogeology

Aquifer type: Single to multi-layered aquifer

Degree of confinement: Mainly unconfined – confined in places

Main Lithology: Sediments - sands and sedimentary rocks - sandstone



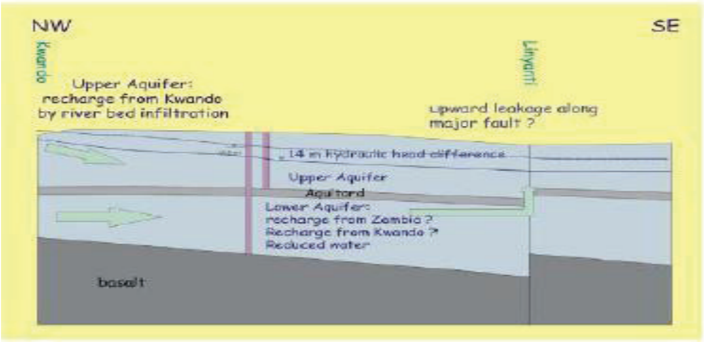


Figure 41: Schematic Concept showing the Structure of the Aquifer System in the Eastern Caprivi

Geological Cross-section of the aquifer system in the Eastern Caprivi - Namibia

Map and cross-section are only provided for illustrative purposes. Dimensions are only approximate

Transboundary Aquifer Information Sheet

AF14 - Nata Karoo Sub-Basin - Caprivi Aquifer (Namibia)

TWAP Groundwater Indicators from Global Inventory

	Recharge (mm/y) (1)	Renewable groundwater per capita (m^3/y/capita)	Natural background groundwater quality (%) (2)	Human dependency on groundwater (%)	Groundwater depletion (mm/y)	Groundwater pollution (%) (3)	Population density (Persons/km2)	Groundwater development stress (%) (4)	Transboundary legal framework (Scores) (5)	Transboundary institutional framework (Scores) (6)
Angola							2			
Botswana							1			
Namibia	1	240	40	75	0		4	35	D	B
Zambia	2	450	95		33	B	5	15	B	D
Zimbabwe							4			
TBA level							**3**			

(1) Recharge: This is the long term average recharge (in m^3/yr) divided by the surface area (m^2) of the complete country segment of the aquifer (i.e. not only the recharge area).

(2) Natural background groundwater quality: Estimate of percentage of surface area of aquifer where the natural groundwater quality satisfies local drinking water standards.

(3) Groundwater pollution: A. No pollution has been identified; B. Some pollution has been identified; Positive number: Significant pollution has been identified (% of surface area of aquifer).

(4) Groundwater development stress: Annual groundwater abstraction divided by recharge.

(5) Legal framework: A. Agreement with full scope for TBA management signed by all parties; B. Agreement with limited scope for TBA management signed by all parties; C. Agreement under preparation or available as an unsigned draft; D. No agreement exists, nor under preparation; E. Legal Framework differs between Aquifer States (see data at National level).

(6) Institutional Framework: A. Dedicated transboundary institution fully operational; B. Dedicated transboundary institution in place, but not fully operational; C. National/Domestic institution fully operational; D. National/Domestic institution in place, but not fully operational; E. No institution exists for TBA management; F. Institutional Framework differs between Aquifer States (see data at National level).

X A value was provided in the questionnaire, but it was considered un-realistic and therefore removed from the table.

TWAP Groundwater Indicators from WaterGAP model

	Recharge, incl. recharge from irrigation (mm/yr)	Renewable groundwater per capita			Human dependency on groundwater (%)	Human dependency on groundwater for domestic water supply (%)	Human dependency on groundwater for irrigation (%)	Human dependency on groundwater for industrial water use(%)
		Current state (m^3/y/capita)	Projection 2030 (% change to current state)	Projection 2050 (% change to current state)				
Angola	260	130 000	-45	-70	9	9	0	0
Botswana	170	95 000	-28	-47	29	40	1	67
Namibia	410	100 000	-29	-46	18	36	0	67
Zambia	160	32 000	-45	-71	4	28	0	0
Zimbabwe	780	110 000	-42	-66	6	28	3	0
TBA level	**230**	**65 000**	**-41**	**-66**	**10**	**33**	**1**	**67**

Transboundary Aquifer Information Sheet

AF14 - Nata Karoo Sub-Basin - Caprivi Aquifer (Namibia)

	Groundwater depletion (mm/y)	Population density			Groundwater development stress		
		Current state (Persons/km2)	Projection 2030 (% change to current state)	Projection 2050 (% change to current state)	Current state (%)	Projection 2030 (% point change to current state)	Projection 2050 (% point change to current state)
Angola	-4	2	72	190	0	0	0
Botswana	-3	2	35	72	<1	0	0
Namibia	-3	4	39	75	<1	0	0
Zambia	-1	5	85	240	<1	0	0
Zimbabwe	0	7	73	200	<1	0	0
TBA level	**-2**	**4**	**67**	**180**	<1	**0**	**0**

Key parameters table from Global Inventory

	Distance from ground surface to groundwater table (m)	Depth to top of aquifer formation (m)	Full vertical thickness of the aquifer (system)* (m)	Degree of confinement	Predominant aquifer lithology	Predominant type of porosity (or voids)	Secondary Porosity	Transmissivity (m^2/d)
Angola								
Botswana								
Namibia	13**	130**	190	Aquifer Mostly unconfined, but some parts confined	Sediment - Sand	High Primary porosity fine/ medium sedimentary deposits	No Secondary porosity	190
Zambia	20**	24**	18	Whole Aquifer unconfined	Sediment - Gravel	High Primary porosity fine/ medium sedimentary deposits	No Secondary porosity	25
Zimbabwe								
TBA level								

* Including aquitards/aquicludes

** These values would need revision as a groundwater table higher than depth to top of the aquifer is un-realistic for an unconfined aquifer.

X A value was provided in the questionnaire, but it was considered un-realistic and therefore removed from the table.

Aquifer description

Aquifer geometry

Regionally this is largely a single-layered system within the unconfined Kalahari sediments. In Namibia and stretching into Botswana it is a two-layered system and a deep-seated confined Caprivi aquifer underlies the shallower aquifer. The average depth to the water table varies from 13 m (Namibia) to 20 m (Zambia). The average depth to the top of the shallower aquifer is 24 m (Zambia)

Transboundary Aquifer Information Sheet

AF14 - Nata Karoo Sub-Basin - Caprivi Aquifer (Namibia)

and the average depth to the top of the deeper aquifer is 128 m (Namibia). The average thickness of the aquifer system varies from 18 m (Zambia) to 190 m (Namibia).

Hydrogeological aspects

The predominant lithology is sediments – sands that are underlain by consolidated sedimentary rocks – sandstone. The formations have a high primary porosity with no secondary porosity and a high vertical and horizontal connectivity. The shallower aquifer is characterized by a relatively low transmissivity value with an average value of 25 m^2/day (Zambia) whereas the deep-seated aquifer has an average value of 190 m^2/day (Namibia). The total groundwater volume within part of the aquifer is estimated at 40 km^3 (Namibia, Zambia). The total mean annual groundwater recharge is 95 million m^3/yr over an area of about 85 000 km^2 (Namibia, Zambia). During extreme events this figure rises to 117 million m^3/yr.

Linkages with other water systems

The predominant source of recharge is through precipitation over the aquifer area with some infiltration from rivers in the northern parts of the aquifer. The predominant discharge mechanism is through evapotranspiration and through groundwater flow into surrounding aquifers (Namibia, Zambia).

Environmental aspects

Between 5% (Zambia) and 60% (Namibia) of the shallower aquifer is not suitable for human consumption. This is mainly due to high salinity and fluoride levels (see Appendix). The deep-seated aquifer has generally fresh water although elevated fluoride levels in places have been noticed. Anthropogenic pollution within the aquifer is limited (Namibia) whereas it is around 10% (Zambia), mainly within the superficial layers. Around 10% of the aquifer area contains shallow groundwater, and around 9% of the area is covered with groundwater-dependent ecosystems (Namibia).

Socio-economic aspects

During 2010 the estimated annual groundwater abstraction was around 15.5million m^3 (Namibia, Zambia). The total fresh water abstraction over the aquifer area was estimated at around 7.4 million m^3 (Namibia).

Legal and Institutional aspects

No formal TBA Agreement exists, and although a dedicated Transboundary River Basin Institution exists through ZAMCOM, it has a limited mandate and capacity for groundwater. The National Institutes have a limited mandate and capacity (Namibia, Zambia).

Emerging and Priority Issues

The adequate management and extent of the deep-seated aquifer must be further explored. The removal of high fluoride contents, for drinking water purposes, in an economical way, within parts of the lower deep-seated aquifer, that is otherwise of good quality, should receive further attention.

Contributors to Global Inventory

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Transboundary Aquifer Information Sheet

AF14 - Nata Karoo Sub-Basin - Caprivi Aquifer (Namibia)

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Considerations and recommendations

Most data in the tables and text above have been provided by national and regional experts (listed above) or have been derived from the global WaterGAP model. See colophon for more information, including references to data from other sources.

Only 2 of the 5 TBA countries have provided information. The information was adequate to describe the aquifer in general terms. The quantitative information did allow the calculation of the indicators at the relevant national levels.

Data gaps and also differences between data from national experts (Global Inventory) and data derived from WaterGAP highlight the need for further research on transboundary aquifers.

Appendix: AF14

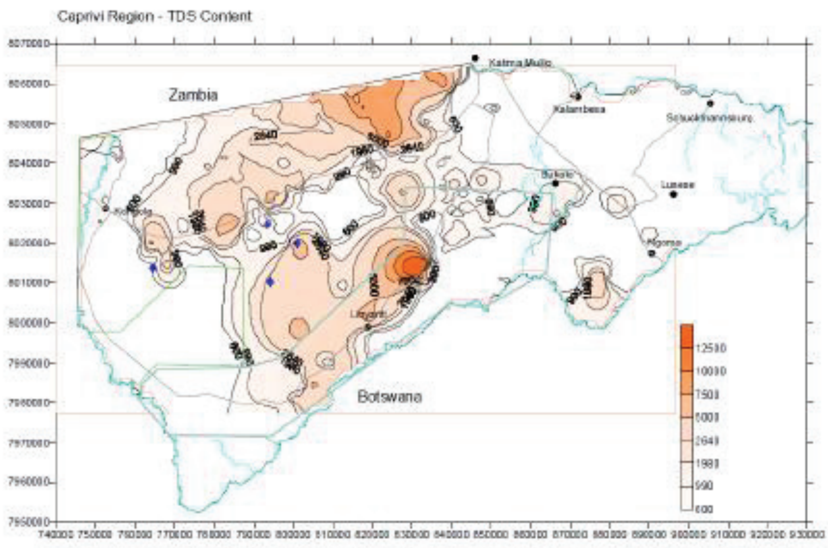


Figure 38: Distribution of Total Dissolved Solids (TDS; in mg/l) in the Upper Aquifer (grey line: HEM survey area; blue symbols: new DWA-BGR boreholes)

Groundwater salinity contours within the Namibia side

Transboundary Aquifer Information Sheet

EU283 – Belgian-Dutch-German Lowland Aquifer System

Geography

Total area TBA (km^2): 49 000

No. countries sharing: 3

Countries sharing: Belgium, Germany, the Netherlands

Population: 24 000 000

Climate zone: Marine

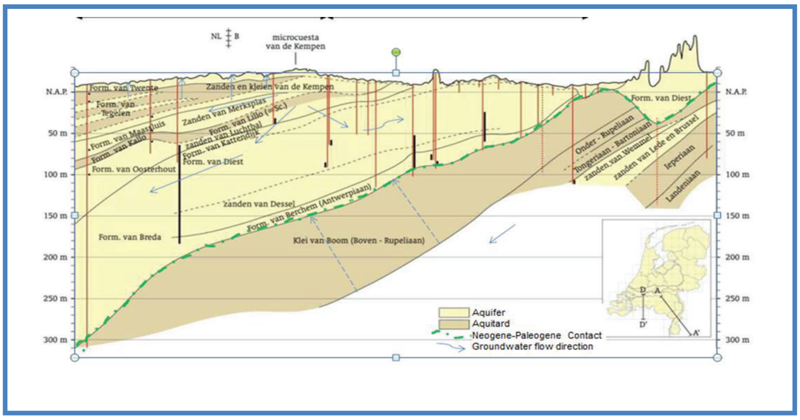
Rainfall (mm/yr): 790

Hydrogeology

Aquifer type: Multiple layers hydraulically connected

Degree of confinement: Mixed conditions

Main Lithology: Sediment - Sand



Cross-section across part of the Aquifer (NW – SE)

Map and cross-section are only provided for illustrative purposes. Dimensions are only approximate

Transboundary Aquifer Information Sheet

EU283 – Belgian-Dutch-German Lowland Aquifer System

TWAP Groundwater Indicators from Global Inventory

	Recharge (mm/y) (1)	Renewable groundwater per capita (m^3/y/capita)	Natural background groundwater quality (%) (2)	Human dependency on groundwater (%)	Groundwater depletion (mm/y)	Groundwater pollution (%) (3)	Population density (Persons/km2)	Groundwater development stress (%) (4)	Transboundary legal framework (Scores) (5)	Transboundary institutional framework (Scores) (6)
Belgium					0		420		D	E
Germany	140	240			0		600		D	E
Netherlands	77	170	65	10	23		460	35	B	C
TBA level							**490**		**E**	**F**

(1) Recharge: This is the long term average recharge (in m^3/yr) divided by the surface area (m^2) of the complete country segment of the aquifer (i.e. not only the recharge area).

(2) Natural background groundwater quality: Estimate of percentage of surface area of aquifer where the natural groundwater quality satisfies local drinking water standards.

(3) Groundwater pollution: A. No pollution has been identified; B. Some pollution has been identified; Positive number: Significant pollution has been identified (% of surface area of aquifer).

(4) Groundwater development stress: Annual groundwater abstraction divided by recharge.

(5) Legal framework: A. Agreement with full scope for TBA management signed by all parties; B. Agreement with limited scope for TBA management signed by all parties; C. Agreement under preparation or available as an unsigned draft; D. No agreement exists, nor under preparation; E. Legal Framework differs between Aquifer States (see data at National level).

(6) Institutional Framework: A. Dedicated transboundary institution fully operational; B. Dedicated transboundary institution in place, but not fully operational; C. National/Domestic institution fully operational; D. National/Domestic institution in place, but not fully operational; E. No institution exists for TBA management; F. Institutional Framework differs between Aquifer States (see data at National level).

X A value was provided in the questionnaire, but it was considered un-realistic and therefore removed from the table.

TWAP Groundwater Indicators from WaterGAP model

	Recharge, incl. recharge from irrigation (mm/yr)	Renewable groundwater per capita			Human dependency on groundwater (%)	Human dependency on groundwater for domestic water supply (%)	Human dependency on groundwater for irrigation (%)	Human dependency on groundwater for industrial water use(%)
		Current state (m^3/y/capita)	Projection 2030 (% change to current state)	Projection 2050 (% change to current state)				
Belgium	300	660	-4	-4	13	45	80	6
Germany	210	360	5	13	12	42	82	6
Netherlands	280	600	0	3	7	26	50	3
TBA level	**270**	**540**	**1**	**5**	**8**	**30**	**57**	**4**

	Groundwater depletion (mm/y)	Population density			Groundwater development stress		
		Current state (Persons/km2)	Projection 2030 (% change to current state)	Projection 2050 (% change to current state)	Current state (%)	Projection 2030 (% point change to current state)	Projection 2050 (% point change to current state)
Belgium	5	460	4	4	9	0	1
Germany	3	570	-4	-12	13	0	0

Transboundary Aquifer Information Sheet

EU283 – Belgian-Dutch-German Lowland Aquifer System

		Population density			Groundwater development stress		
	Groundwater depletion (mm/y)	Current state (Persons/km2)	Projection 2030 (% change to current state)	Projection 2050 (% change to current state)	Current state (%)	Projection 2030 (% point change to current state)	Projection 2050 (% point change to current state)
Netherlands	4	470	3	0	8	0	0
TBA level	**4**	**490**	**1**	**-2**	**9**	**0**	**0**

Key parameters table from Global Inventory

	Distance from ground surface to groundwater table (m)	Depth to top of aquifer formation (m)	Full vertical thickness of the aquifer (system)* (m)	Degree of confinement	Predominant aquifer lithology	Primary Porosity	Secondary Porosity	Transmissivity (m^2/d)
Belgium				Aquifer mostly unconfined, but some parts confined	Sediment - Sand	High primary porosity fine/ medium sedimentary deposits	Secondary porosity: Fractures	
Germany	5	5	500	Aquifer mostly confined, but some parts unconfined	Sediment - Sand	High primary porosity fine medium sedimentary deposits	No secondary porosity	200
Netherlands	<5	<5	1 000	Aquifer mostly semi-confined, but some parts unconfined	Sediment - Sand	High primary porosity fine/ medium sedimentary deposits	No secondary porosity	4000
TBA level								

* Including aquitards/aquicludes

X A value was provided in the questionnaire, but it was considered un-realistic and therefore removed from the table.

Aquifer description

Aquifer geometry

The Transboundary Aquifer system stretches across the national boundaries of Belgium, Germany and The Netherlands. It is a multiple-layered hydraulically connected system that has between eight and ten main water-bearing horizons. The average depth to the water table and the average depth to the top of the aquifer is < 5m in both reporting countries. The average vertical thickness of the aquifer system varies between 500 m – 1 000 m as reported by Germany and the Netherlands.

Transboundary Aquifer Information Sheet

EU283 – Belgian-Dutch-German Lowland Aquifer System

Hydrogeological aspects

The aquifer system is composed of sandy and clayey Tertiary and Quaternary sedimentary materials, which are hydraulically connected, and are dipping towards The Netherlands; it has a highly variable thickness. The aquifer has a high primary porosity as well as secondary porosity (fractures) giving it a high horizontal and a low vertical connectivity. The groundwater volume is approximately 1 400km^3 in the Netherlands and Germany.

Links with other water systems

Groundwater flow is mainly controlled by surface flow (Ems, Vechte River) and the average groundwater levels range between 2 m and 5 m. Recharge, from precipitation and diffuse discharge (seepage zones), is widely distributed in Holland, and evapotranspiration and river base flow are the main aquifer outputs. Groundwater-dependent ecosystems cover an important part of the aquifer.

Environmental aspects

The semi-confined aquifer system is characterized by a brackish to saline groundwater at a depth, which varies considerable (connate water interface from less than 110 m and more than than 500 m deep), underlying the fresh upper water zone of the aquifer. In the Netherlands about 35% of the aquifer over the whole thickness is unsuitable for human consumption mainly because of elevated salinity levels. Some pollution, which is significant in the Netherlands, in the superficial layers has occurred, but the percentage of the aquifer affected has not been recorded. Local impacts are mainly groundwater pollution originating at the land surface, and groundwater abstractions on the Netherlands side. Some pollution has been identified, of natural geochemical origin (salinity, As, Ni), also from agricultural practices, and industrial wastes (organic compounds). Between 55% and 85% of the aquifer in the aquifer states have shallow groundwater with between 3% and 75% of the aquifer area being covered with groundwater-dependent ecosystems in Germany and the Netherlands (see Appendix). However, these groundwater-dependent ecosystems may not all be associated with the transboundary aquifer, i.e. they may rely on local national aquifers.

Socio-economic aspects

The aquifer area has a very high population density. The fresh aquifer is relatively shallow and is exploited for water supply and irrigation. The total amount of groundwater abstracted during 2010 in the Netherlands and Belgium was 1 200 million m^3. The total amount of fresh water utilised over the aquifer area in Belgium over the same period was 10 000 million m^3 .

Legal and Institutional aspects

A limited Multilateral Legal Agreement (Germany, The Netherlands) has been ratified for the Transboundary Aquifer Management; the country legislation applies at the National level. No Transboundary Institution has yet been established.

Hotspots

Large-scale mining activities are foreseen. Potential threats to groundwater flow and quality in this transboundary aquifer system are: lignite mining (Nordrhein - Westphalen), natural gas exploitation (Groningen), subsurface storage of gas, potential subsurface storage of hazardous waste (Boom clay), and external pressures (e.g. land use, surface-groundwater interaction by rivers entering in the system and human activities). Vulnerability associated with mining, waste disposal, possible acid mine drainage and groundwater abstraction to lower groundwater levels are seen as hotspot issues.

Transboundary Aquifer Information Sheet

EU283 – Belgian-Dutch-German Lowland Aquifer System

Contributors to Global Inventory

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Considerations and recommendations

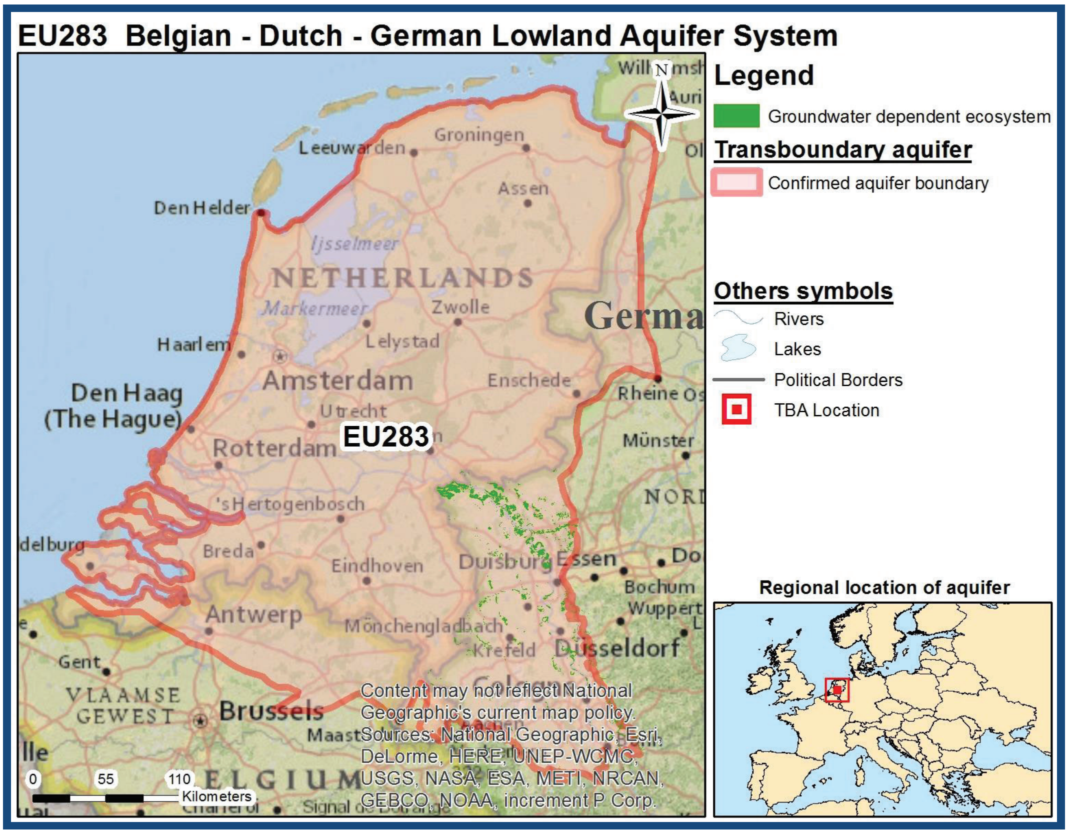
Most data in the above tables and text have been provided by national and regional experts (listed above) or derived from the global WaterGAP model. See colophon for more information, including references to data from other sources.

All aspects of the aquifer geometry and parameters have been addressed using consistent and realistic information, allowing indicator estimates at the TBA level.

Data gaps, and differences between data from national experts (Global Inventory) and data derived from WaterGAP, highlight the need for further research on transboundary aquifers.

Transboundary Aquifer Information Sheet

EU283 – Belgian-Dutch-German Lowland Aquifer System



Map showing groundwater dependent ecosystems within the Belgian-Dutch-German Lowland Aquifer System

Please note: Information has only been provided for the German part of the aquifer.

Transboundary Aquifer Information Sheet

AS126 - Saq-Ram Aquifer System (West)

Geography

Total area TBA (km^2): 150 000

No. countries sharing: 2

Countries sharing: Jordan, Saudi Arabia

Population: 4 400 000

Climate zone: Arid

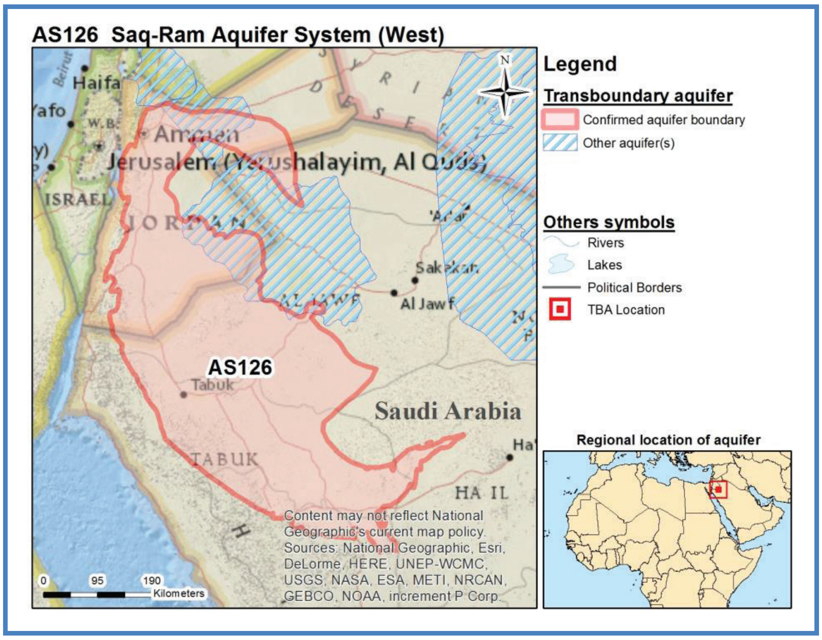
Rainfall (mm/yr): 74

Hydrogeology

Aquifer type: Multiple 3-layered, hydraulically connected

Degree of confinement: Mostly confined, some parts unconfined

Main Lithology: Sedimentary rocks - sandstones



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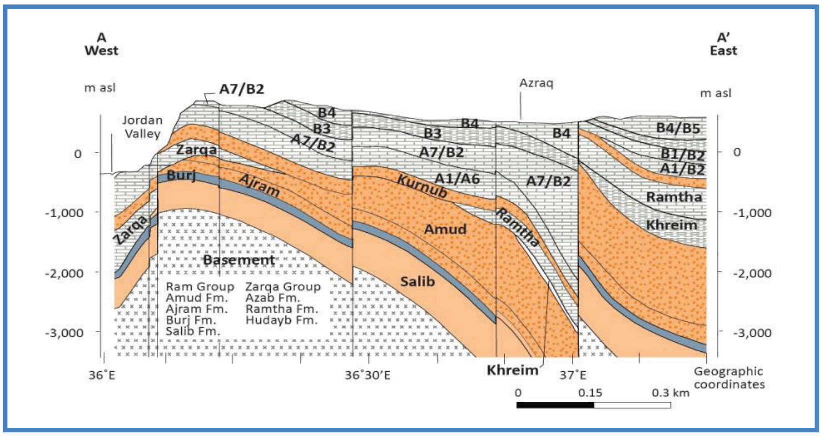

Geological Cross-section across part of the Aquifer (E – W)

Map and cross-section are only provided for illustrative purposes. Dimensions are only approximate.

Transboundary Aquifer Information Sheet

AS126 - Saq-Ram Aquifer System (West)

TWAP Groundwater Indicators from Global Inventory

	Recharge (mm/y) (1)	Renewable groundwater per capita (m^3/y/capita)	Natural background groundwater quality (%) (2)	Human dependency on groundwater (%)	Groundwater depletion (mm/y)	Groundwater pollution (%) (3)	Population density (Persons/km2)	Groundwater development stress (%) (4)	Transboundary legal framework (Scores) (5)	Transboundary institutional framework (Scores) (6)
Jordan							81			
Saudi Arabia							6			
TBA level	**1**	**20**	**70**		**X**	**B**	**29**	**>1 000**	**E**	**F**

(1) Recharge: This is the long term average recharge (in m^3/yr) divided by the surface area (m^2) of the complete country segment of the aquifer (i.e. not only the recharge area).

(2) Natural background groundwater quality: Estimate of percentage of surface area of aquifer where the natural groundwater quality satisfies local drinking water standards.

(3) Groundwater pollution: A. No pollution has been identified; B. Some pollution has been identified; Positive number: Significant pollution has been identified (% of surface area of aquifer).

(4) Groundwater development stress: Annual groundwater abstraction divided by recharge.

(5) Legal framework: A. Agreement with full scope for TBA management signed by all parties; B. Agreement with limited scope for TBA management signed by all parties; C. Agreement under preparation or available as an unsigned draft; D. No agreement exists, nor under preparation; E. Legal Framework differs between Aquifer States (see data at National level).

(6) Institutional Framework: A. Dedicated transboundary institution fully operational; B. Dedicated transboundary institution in place, but not fully operational; C. National/Domestic institution fully operational; D. National/Domestic institution in place, but not fully operational; E. No institution exists for TBA management; F. Institutional Framework differs between Aquifer States (see data at National level).

X A value was provided in the questionnaire, but it was considered un-realistic and therefore removed from the table.

Key parameters table from Global Inventory

	Distance from ground surface to groundwater table (m)	Depth to top of aquifer formation (m)	Full vertical thickness of the aquifer (system)* (m)	Degree of confinement	Predominant aquifer lithology	Predominant type of porosity (or voids)	Secondary Porosity	Av. Transmissivity (m^2/d)
Jordan								
Saudi Arabia								
TBA level				**Aquifer mostly confined, but some parts unconfined**	**Sedimentary rock: Sandstone**	**High primary porosity fine/medium sedimentary deposits**		**1 300**

* Including aquitards/aquicludes

X A value was provided in the questionnaire, but it was considered un-realistic and therefore removed from the table.

Transboundary Aquifer Information Sheet

AS126 - Saq-Ram Aquifer System (West)

Aquifer description

Aquifer geometry

Geo-structural and physiographic features as well as the approximate extent of exploitable area were used to approximate the boundaries of this western transboundary part of the system as opposed to an eastern part lying entirely within Saudi Arabia. The system comprises three hydraulically connected layers. It is mostly confined although some parts are unconfined. The thickness of the aquifer system, including aquitards, varies from 250m to 2 500m.

Hydrogeological aspects

The dominant aquifer lithology is sedimentary rocks – sandstones. The system normally receives a recharge of about 90Mm^3/annum of freshwater that may increase to nearly 400 Mm^3/annum due to extreme events. The freshwater percolates through a recharge area of approximately 35 000 km^2. Primary type of porosity is predominant that allows low vertical connectivity between layers. Transmissivity values recorded across the aquifer states range between 3 700 and 90 m^2/d with an average of 1 300 m^2/d.

Links with other water systems

There is evidence for a limited amount of recharge in high plateau and escarpment areas through the sandstones outcrop. The main and final discharge zone for the system is the Dead Sea but some discharge also occurs en-route in the form of springs and baseflow in deeply incised wadis that eventually discharge into the Dead Sea (see Appendix 1).

Environmental aspects

Groundwater quality does not satisfy local drinking water standards in about 30% of aquifer area, mainly in the superficial layers of the aquifer system that become vulnerable to pollution from agricultural practice. Rising levels of salinity and nitrates have been observed in these areas.

Socio-economic aspects

A total of about 1 130 Mm^3/annum of groundwater is abstracted by the two aquifer states. Abstraction in Jordan is currently significantly less than in Saudi Arabia.

Legal and Institutional aspects

National Institutions for the management of groundwater exist in both aquifer states, and some measures have been taken in recent years to establish some kind of Bilateral Agreement.

Hot spot

The main issue for this TBA is the occurrence of natural nuclides such as radon and radium that could seriously limit the future use of the groundwater. These isotopes may originate from the underlying Basement but are also found in overlying confining layers. The highest concentration of radium isotopes is in confined areas. Detailed studies of such areas are required. Abstraction far exceeds the annual recharge and steps towards joint management need to be speeded up.

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Transboundary Aquifer Information Sheet

AS126 - Saq-Ram Aquifer System (West)

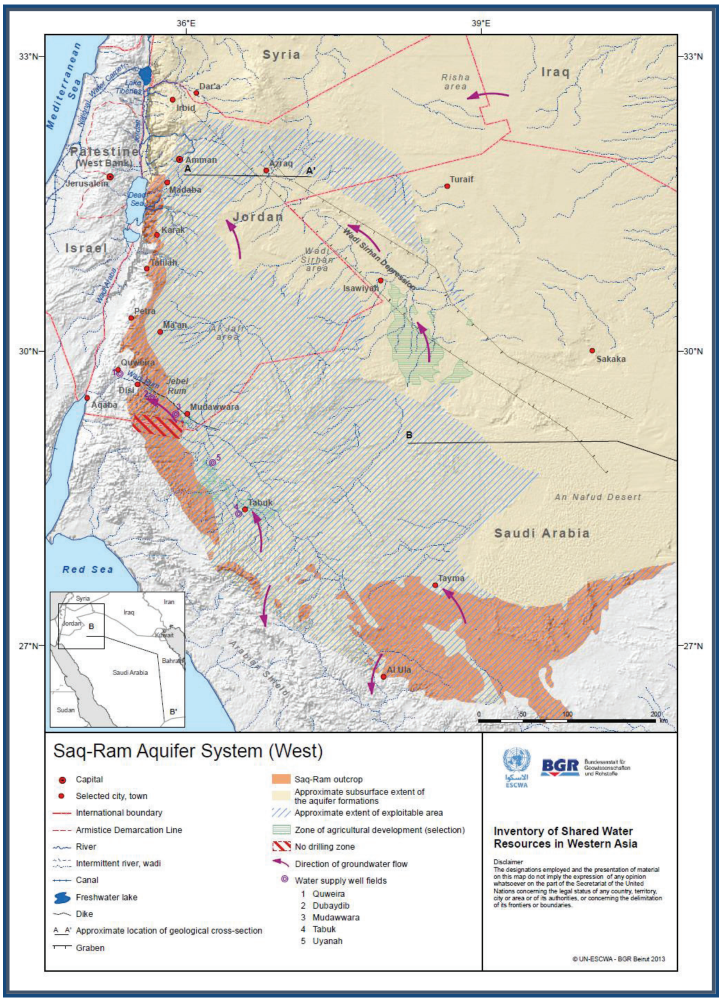
Considerations and recommendations

Most data in the above tables and text have been provided by national and regional experts (listed above) or have been derived from the global WaterGAP model. See colophon for more information, including references to data from other sources.

Both TBA countries contributed to the information. Information was adequate to describe the aquifer in general terms. Some quantitative information was also available, but not enough to calculate indicators.

Data gaps and also differences between data from national experts (Global Inventory) and data derived from WaterGAP highlight the need for further research on transboundary aquifers.

Appendix 1: AS126



Map showing Aquifer flow and discharge within the Saq-Ram Aquifer System (West)

Transboundary Aquifer Information Sheet

AS74 - Tacheng Basin / Alakol

Geography

Total area TBA (km^2): 34 000

No. countries sharing: 2

Countries sharing: Kazakhstan, China

Population: 320 000

Climate Zone: Semi-arid

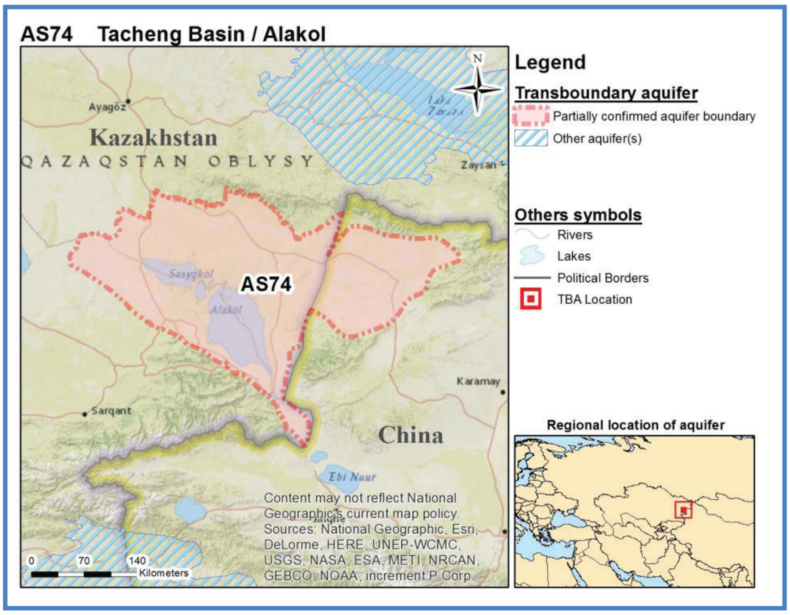
Rainfall (mm/yr): 290

Hydrogeology

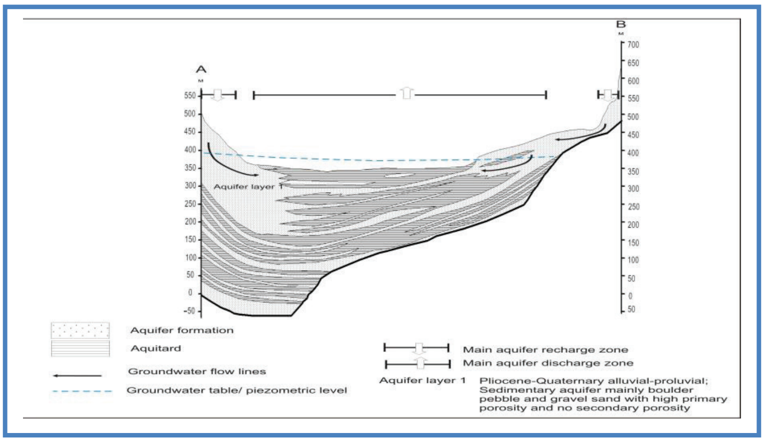
Aquifer type: Single to multi-layered system

Degree of confinement: Confined to Unconfined

Main Lithology: Sediment – sand and gravel



Content may not reflect National Geographic's current map policy. Sources: National Geographic, Esri, DeLorme, HERE, UNEP-WCMC, USGS, NASA, ESA, METI, NRCAN, GEBCO, NOAA, increment P Corp.



Geological cross-section along part of the Tacheng Basin / Alakol showing the main recharge and discharge zones

Map and cross-section are only provided for illustrative purposes. Dimensions are only approximate

Transboundary Aquifer Information Sheet

AS74 - Tacheng Basin / Alakol

TWAP Groundwater Indicators from Global Inventory

	Recharge (mm/y) (1)	Renewable groundwater per capita (m^3/y/capita)	Natural background groundwater quality (%) (2)	Human dependency on groundwater (%)	Groundwater depletion (mm/y)	Groundwater pollution (%) (3)	Population density (Persons/km2)	Groundwater development stress (%) (4)	Transboundary legal framework (Scores) (5)	Transboundary institutional framework (Scores) (6)
China	<1	5	100	50	2 500	A	24	100	A	
Kazakhstan	35	7 100			0		5	<5	D	
TBA level	**26**	**2 900**					**9**	**<5**	**E**	

(1) Recharge: This is the long-term average recharge (in m^3/yr) divided by the surface area (m^2) of the complete country segment of the aquifer (i.e. not only the recharge area).

(2) Natural background groundwater quality: Estimate of percentage of surface area of aquifer where the natural groundwater quality satisfies local drinking water standards.

(3) Groundwater pollution: A. No pollution has been identified; B. Some pollution has been identified; Positive number: Significant pollution has been identified (% of surface area of aquifer).

(4) Groundwater development stress: Annual groundwater abstraction divided by recharge.

(5) Legal framework: A. Agreement with full scope for TBA management signed by all parties; B. Agreement with limited scope for TBA management signed by all parties; C. Agreement under preparation or available as an unsigned draft; D. No agreement exists, nor under preparation; E. Legal Framework differs between Aquifer States (see data at National level).

(6) Institutional Framework: A. Dedicated transboundary institution fully operational; B. Dedicated transboundary institution in place, but not fully operational; C. National/Domestic institution fully operational; D. National/Domestic institution in place, but not fully operational; E. No institution exists for TBA management; F. Institutional Framework differs between Aquifer States (see data at National level).

X A value was provided in the questionnaire, but it was considered unrealistic and therefore removed from the table.

TWAP Groundwater Indicators from WaterGAP model

		Renewable groundwater per capita						
	Recharge, incl. recharge from irrigation (mm/yr)	Current state (m^3/y/capita)	Projection 2030 (% change to current state)	Projection 2050 (% change to current state)	Human dependency on groundwater (%)	Human dependency on groundwater for domestic water supply (%)	Human dependency on groundwater for irrigation (%)	Human dependency on groundwater for industrial water use(%)
China	240	11 000	6	22	11	15	11	5
Kazakhstan	210	42 000	0	-5	7	36	6	8
TBA level	**210**	**24 000**	**5**	**9**	**10**	**28**	**10**	**7**

		Population density			Groundwater development stress		
	Groundwater depletion (mm/y)	Current state (Persons/km2)	Projection 2030 (% change to current state)	Projection 2050 (% change to current state)	Current state (%)	Projection 2030 (% point change to current state)	Projection 2050 (% point change to current state)
China	-1	21	3	-6	21	0	0
Kazakhstan	2	5	15	24	1	0	0
TBA level	**2**	**9**	**9**	**7**	**6**	**0**	**0**

Transboundary Aquifer Information Sheet

Groundwater TWAP TRANSBOUNDARY WATERS ASSESSMENT PROGRAMME

AS74 - Tacheng Basin / Alakol

Key parameters table from Global Inventory

	Distance from ground surface to groundwater table (m)	Depth to top of aquifer formation (m)	Full vertical thickness of the aquifer (system)* (m)	Degree of confinement	Predominant aquifer lithology	Predominant type of porosity (or voids)	Secondary Porosity	Av. Transmissivity (m^2/d)
China	15**	<5**	480	Aquifer Mostly confined, but some parts unconfined	Sediment - Sand	High Primary porosity fine/ medium sedimentary deposits	Secondary porosity: Fractures	2 000
Kazakhstan	<5	<5	100	Aquifer Mostly unconfined, but some parts confined	Sediment - Gravel	High Primary porosity fine/ medium sedimentary deposits	No Secondary porosity	580
TBA level								

* Including aquitards/aquicludes

** These values would need revision as a groundwater table lower than depth to top of the aquifer is un-realistic for a confined aquifer.

X A value was provided in the questionnaire, but it was considered un-realistic and therefore removed from the table.

Aquifer description

Aquifer geometry

This is a single to multi-layered system that varies from mainly confined to unconfined conditions. The average depth to the water table varies from <5 – 15 m. The average depth to the top of the aquifer is <5 m while the average thickness of the aquifer system varies from 100 m in Kazakhstan to 480 m in China.

Hydrogeological aspects

The predominant aquifer lithology is sediment – sand and gravel that has a high primary porosity. In China secondary porosity (fractures) also occur. The formation is characterized by a high horizontal and vertical connectivity. The average transmissivity values range from 580 – 2 000 m^2/day. The total groundwater volume within the system is 270 km^3. The average recharge into the system, that is 100% through natural recharge, is 910 million m^3/yr and the aerial extent of the major recharge area is 18 000 km^2.

Links with other water systems

The predominant source of recharge is through infiltration from surface water bodies in Kazakhstan and through precipitation over the aquifer area in China. The major discharge mechanism is through outflow into lakes in Kazakhstan and through river base flow in China (see appendix).

Environmental aspects

Besides some natural salinity over parts of the superficial layers, no other significant portion of the aquifer is unsuitable for human consumption. No major anthropogenic groundwater pollution has been identified. 40% of the aquifer in Kazakhstan is characterised by shallow groundwater and 80% of the TBA part in China is reported to be covered by groundwater-dependent ecosystems. However, these groundwater-dependent ecosystems may not all be associated with the transboundary aquifer, i.e. they may rely on local national aquifers.

UNEP gef United Nations Educational, Scientific and Cultural Organization · International Hydrological Programme

Transboundary Aquifer Information Sheet

AS74 - Tacheng Basin / Alakol

Socio-economic aspects

A total of 3.8 million m^3 of water was abstracted from the system during 2010. A total amount of 2 million m^3 of fresh water was abstracted over the aquifer area in China in the same year.

Legal and Institutional aspects

The information on agreements and institutions is not consistent. China makes mention of a signed Bilateral Agreement with full scope, Kazakhstan reports that there is no Agreement in place. China reports that a Transboundary Institute with full mandate and capacity exists, Kazakhstan reports that not even a National Institute with a groundwater mandate currently exists. However, groundwater abstraction is controlled through law/ regulations, and measures are also applied in practice in Kazakhstan.

Emerging Issues

The Transboundary Agreement must be reviewed and adapted for application in both countries. The Institutional set-up within Kazakhstan must be assessed with a view to possible assistance in this regard.

Contributors to Global Inventory

Name	Organisation	Country	E-mail	Role
Sangam Shresta	Asian Institute of Technology	Thailand	sangamshrestha@gmail.com	Regional coordinator
Yao Li	China University of Gesciences, Bejing	China	ly2752@163.com	Contributing national expert
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Liyan Yue	China University of Gesciences, Bejing	China	yueliyan00120@126.com	Contributing national expert
Zaisheng Han	China University of Gesciences, Bejing	China	hanzsh@hotmail.com	Lead National Expert
Aleksandr Kuchin	Hydrogeological research and design company "KazHYDEC" Ltd.	Kazakhstan	agkuchin@gmail.com	Contributing national expert
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Considerations and recommendations

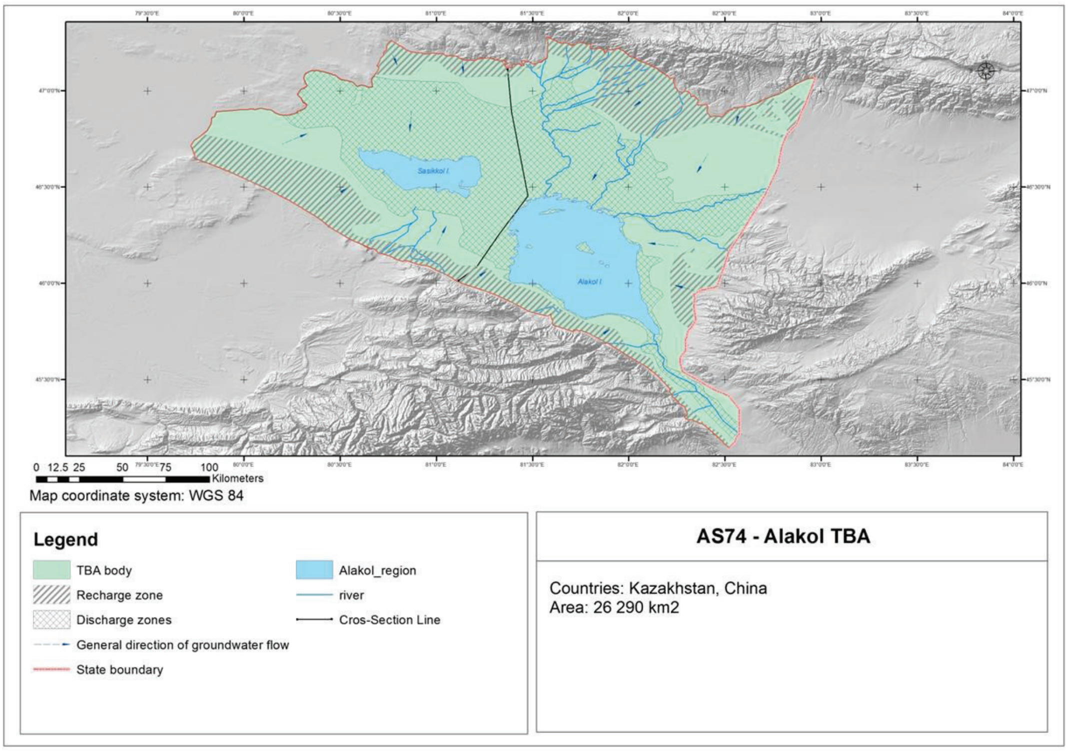
Most data in the tables and text above have been provided by national and regional experts (listed above) or have been derived from the global WaterGAP model. See colophon for more information, including references to data from other sources.

Both transboundary countries have provided adequate technical information, allowing the calculation of some of the indicators at transboundary level. The inconsistent legal/institutional information indicates that transboundary cooperation is not yet occurring in practice.

Data gaps and also differences between data from national experts (Global Inventory) and data derived from WaterGAP highlight the need for further research on transboundary aquifers.

Transboundary Aquifer Information Sheet

AS74 - Tacheng Basin / Alakol



AS74 - Alakol TBA

Countries: Kazakhstan, China
Area: 26 290 km2

Tacheng Basin / Alakol: Groundwater recharge-discharge regime

Appendix 3 – Questionnaire responses: overview by continent or region

A total of 194 TBA Briefs were produced. Since these, together with the database, will form the basis of comparative viewing of TBAs globally and regionally, the information output provided in the different regions and for different information elements is summarized below. For ease of presentation, the main TBA features (Figures 1-8) are shown separately from the information elements of the aquifer description (Figures 9-16).

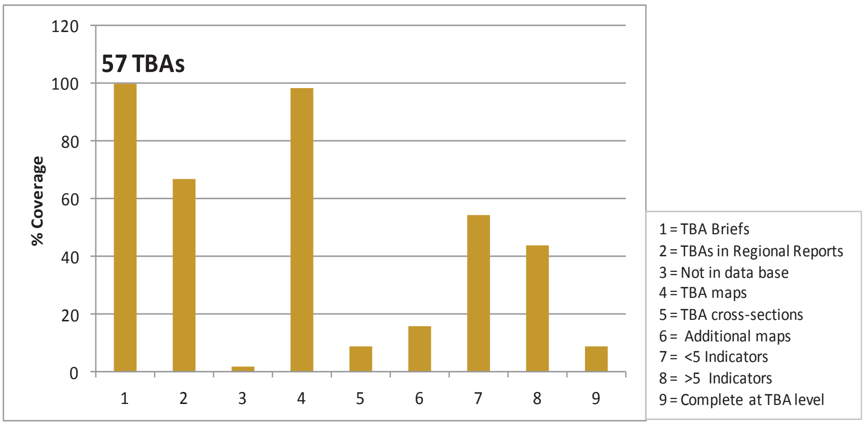


Figure 1: Americas - % Coverage of the various items listed in Table 2

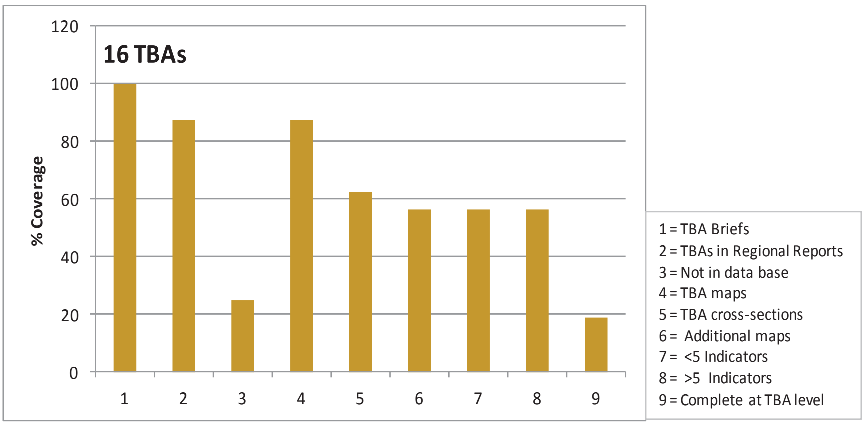


Figure 2: Central Asia - % Coverage of the various items listed in Table 2

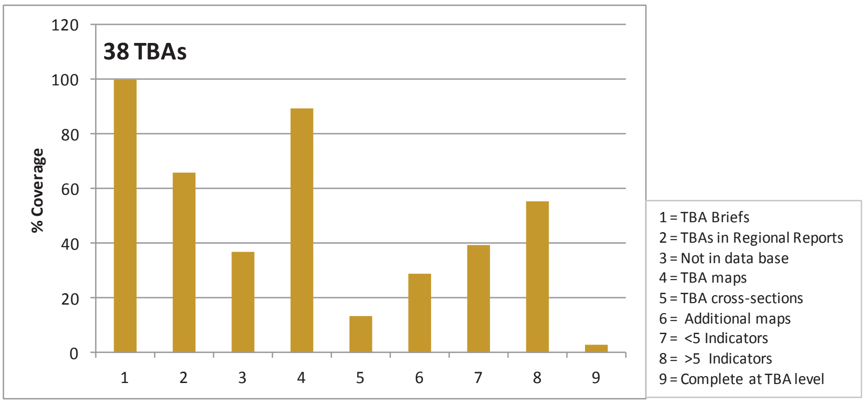


Figure 3: South-East Asia - % Coverage of the various items listed in Table 2

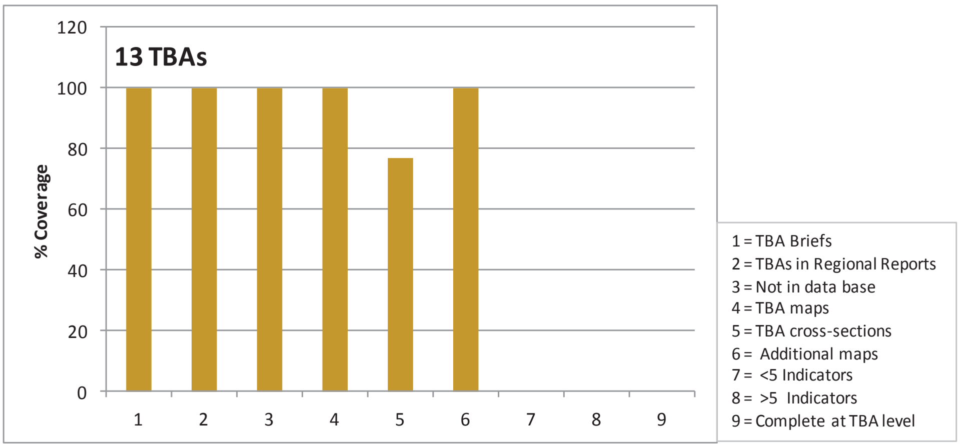


Figure 4: Western Asia - % Coverage of the various items listed in Table 2

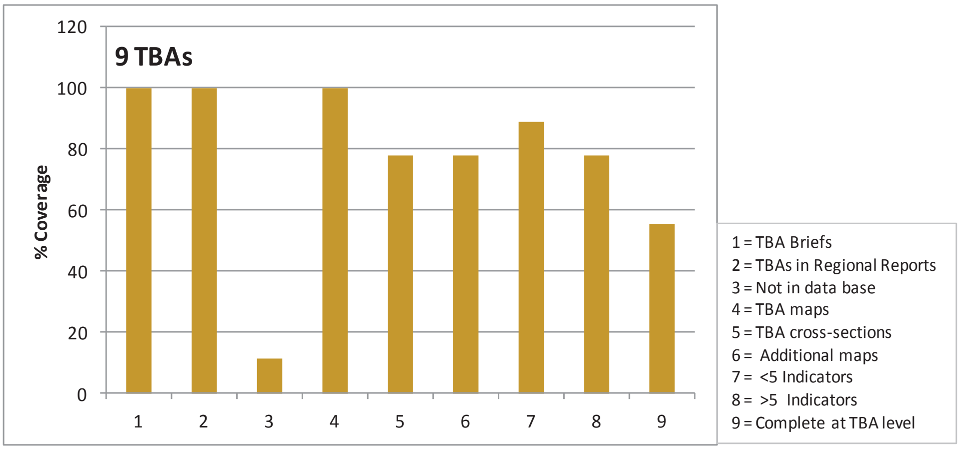


Figure 5: Europe - % Coverage of the various items listed in Table 2

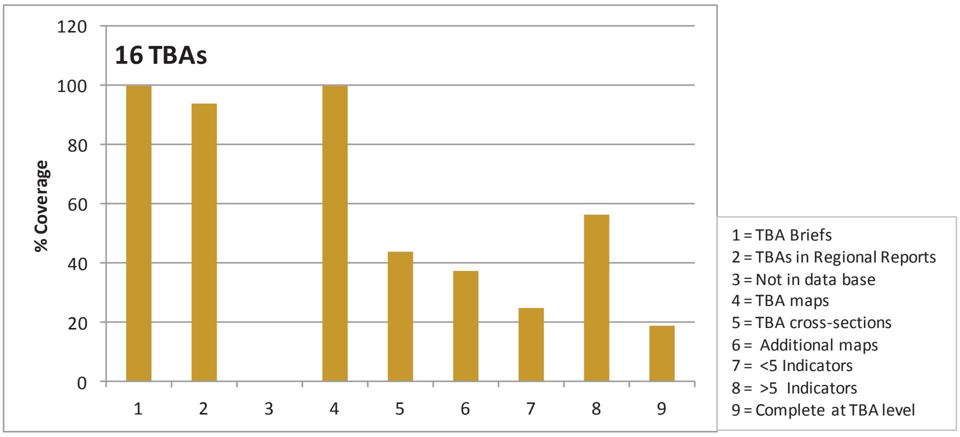


Figure 6: Western & Central Africa - % Coverage of the various items listed in Table 2

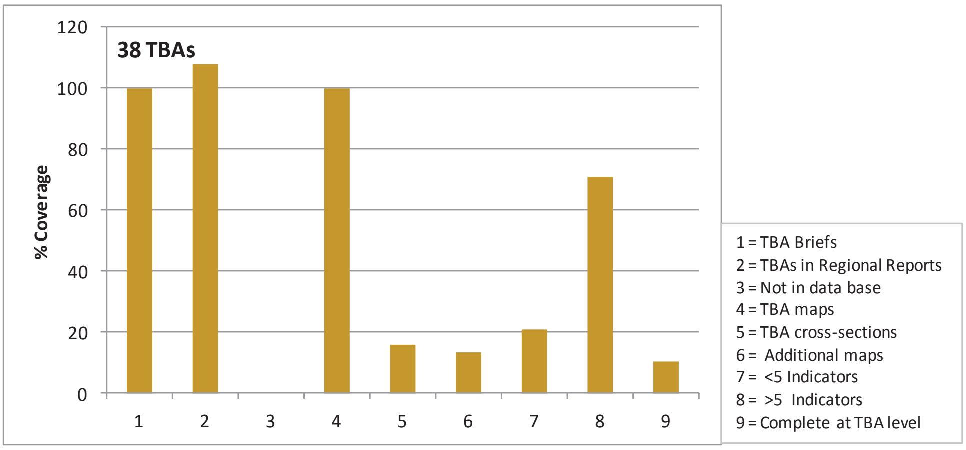


Figure 7: Southern & Eastern Africa - % Coverage of the various items listed in Table 2

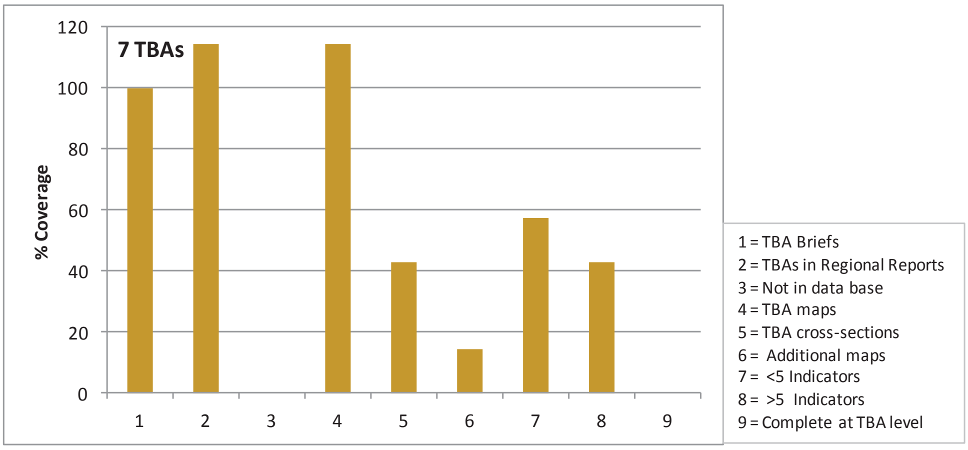


Figure 8: North Africa - % Coverage of the various items listed in Table 2

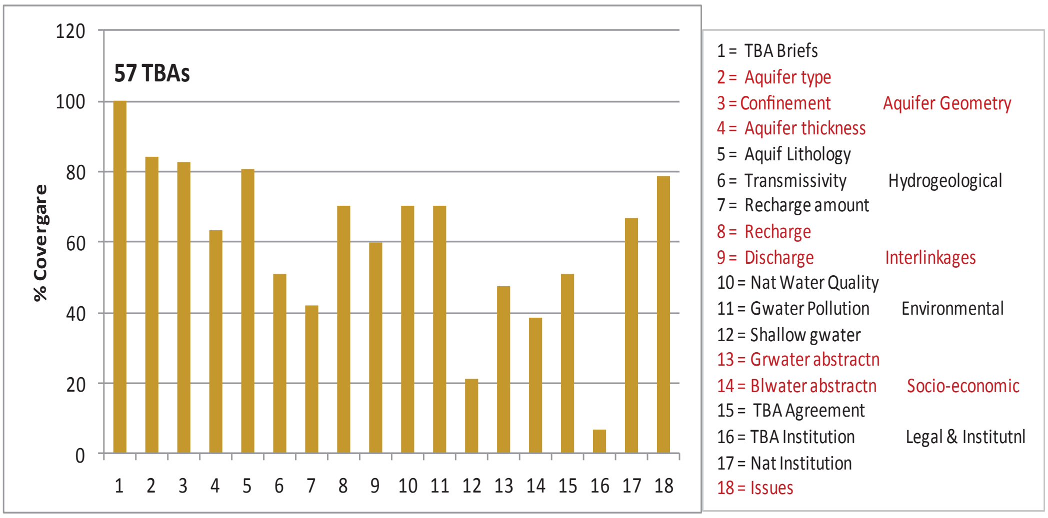


Figure 9: Americas - % Coverage of the various items of the aquifer description

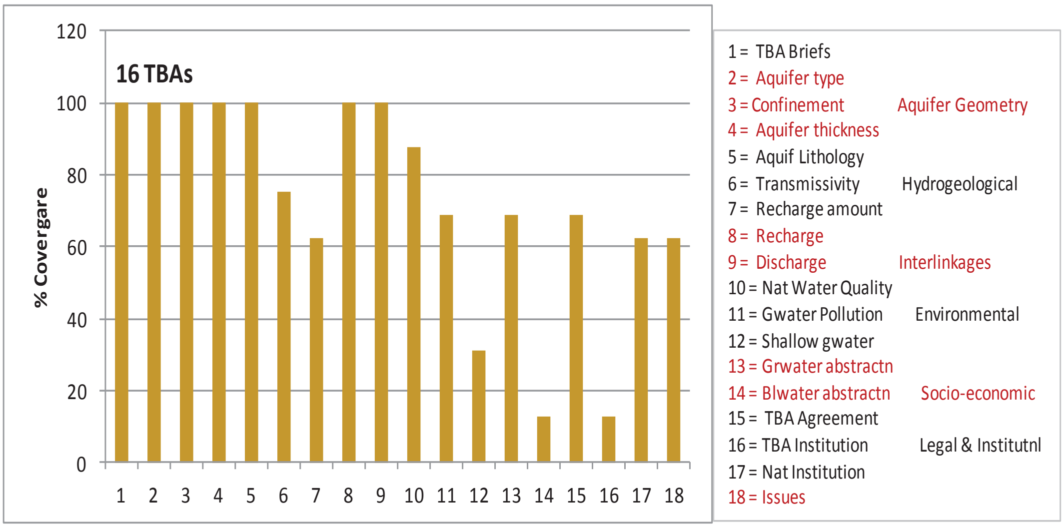


Figure 10: Central Asia- % Coverage of the various items of the aquifer description

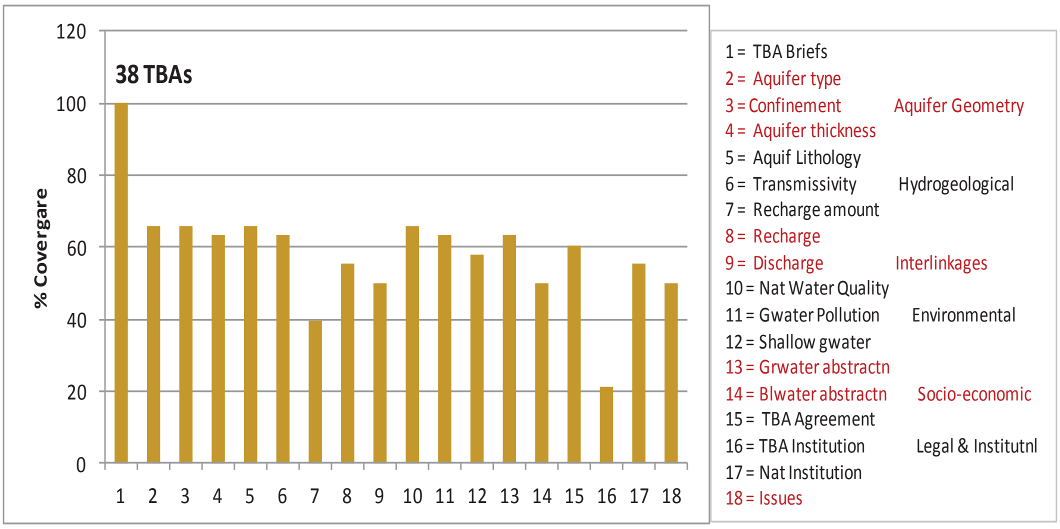


Figure 11: South-East Asia- % Coverage of the various items of the aquifer description

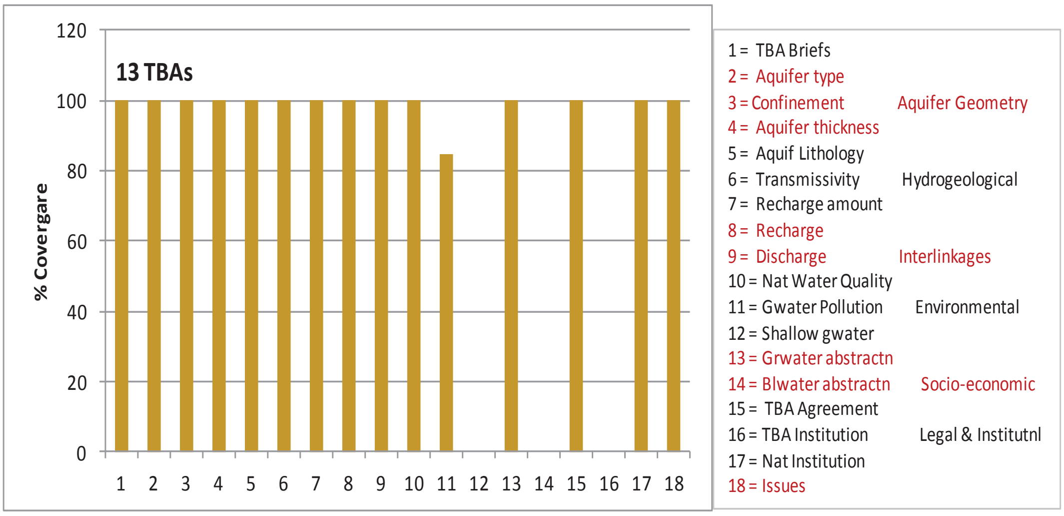


Figure 12: Western Asia- % Coverage of the various items of the aquifer description

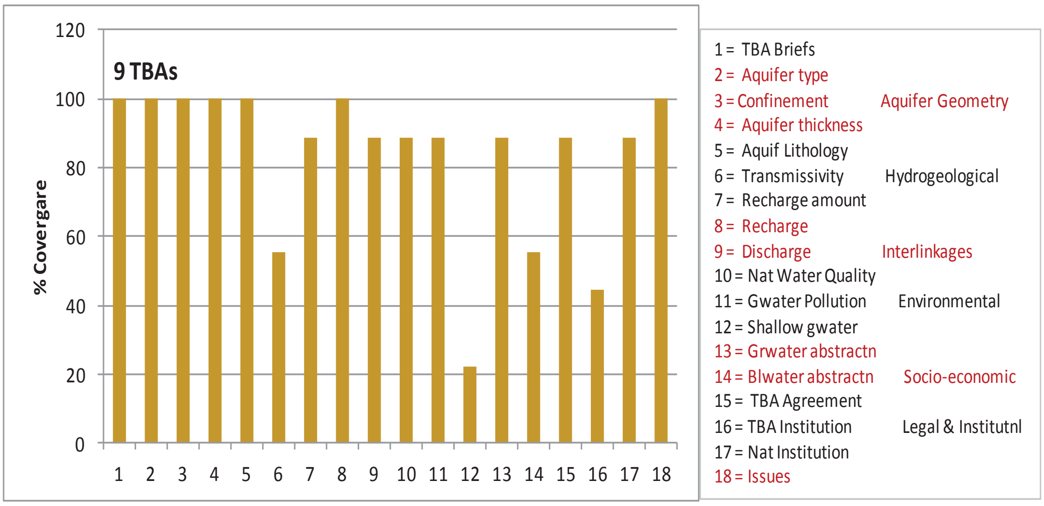


Figure 13: Europe - % Coverage of the various items of the aquifer description

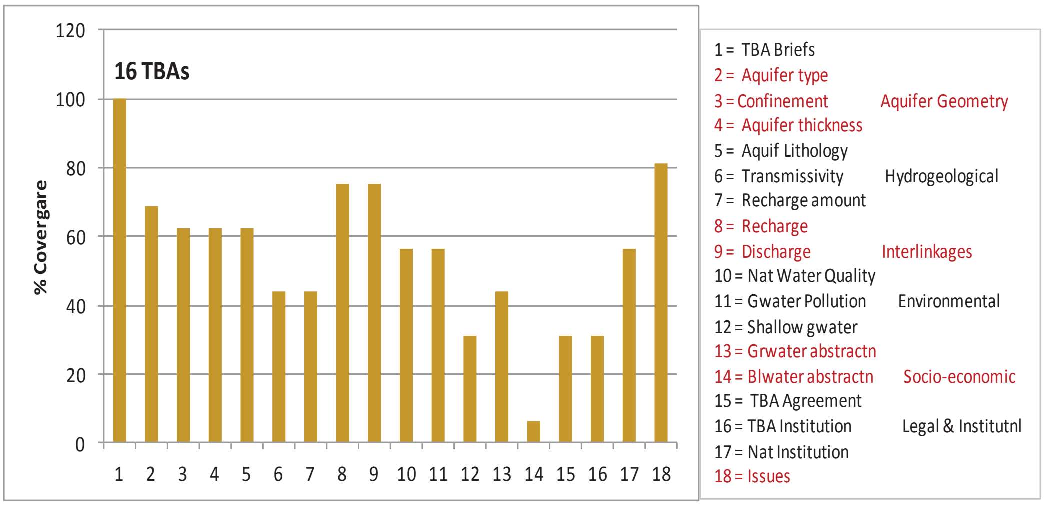


Figure 14: Western- Central Africa - % Coverage of the various items of the aquifer description

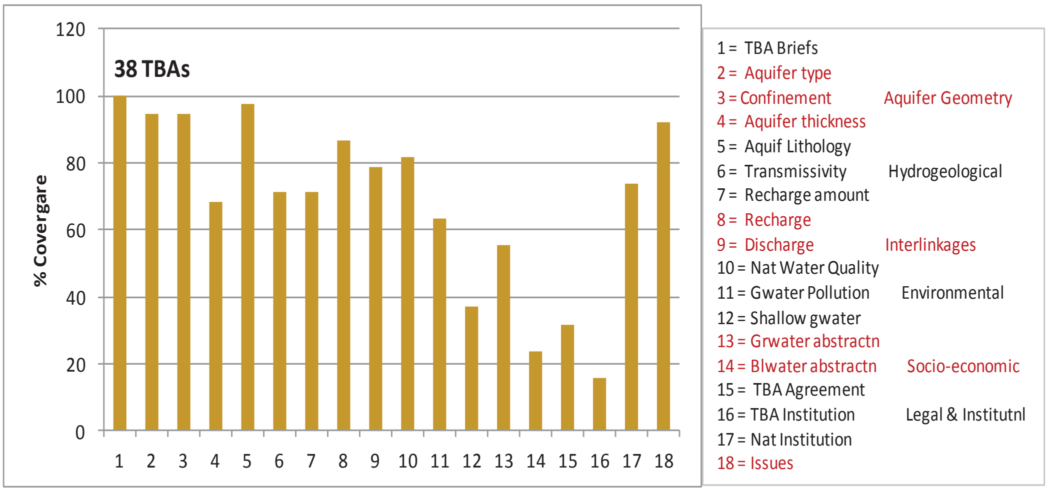


Figure 15: Southern-Eastern Africa - % Coverage of the various items of the aquifer description

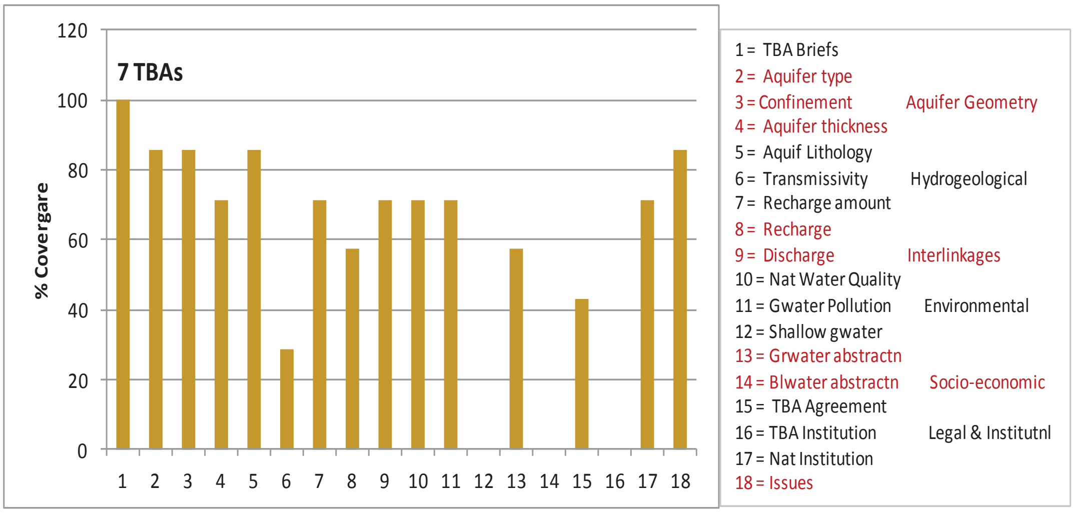


Figure 16: North Africa - % Coverage of the various items of the aquifer description

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Appendix 4 – SIDS Hydrogeological Profiles: examples

Appendix 4-1: Santiago Island - Cape Verde

Appendix 4-2: Jamaica Island - Jamaica

Appendix 4-3: Mahé Island - Maldives

Appendix 4-4: Nauru Island - Nauru

Appendix 4-5: Grande Terre Island - New Caledonia

Appendix 4-6: Saint Kitts Island - Federation of Saint Kitts and Nevis

SANTIAGO ISLAND - CAPE VERDE

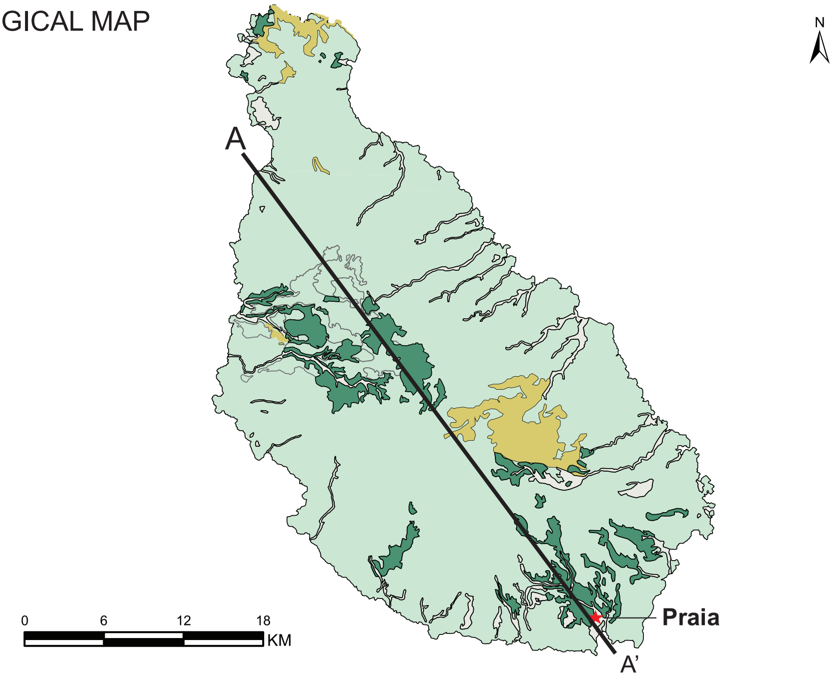
LAT: 15.1111°N LONG: 23.6167 °W

ISLAND STATISTICS

Area (km^2)	991
Max. Elevation (masl)	1344
Aquifer Lithology	Basalt
Average Annual Precipitation (mm/a)	285
Calculated AET (mm/a)	166
Recharge (mm/a)	60
Max. Aquifer Thickness (m)	225
Groundwater Vol. (x10^9 m^3)	66.9
GW Vol. Abstracted (x10^6 m^3/a)	22
Predominant Natural Groundwater Quality	Brackish

REF: DEM: USGS(2004), Shuttle Radar Topography Mission
GEO: Serralheiro, A. (1976). Carta geológica da Ilha de Santiago (Cabo Verde) na escala 1:25000.

GEOLOGICAL MAP



LEGEND

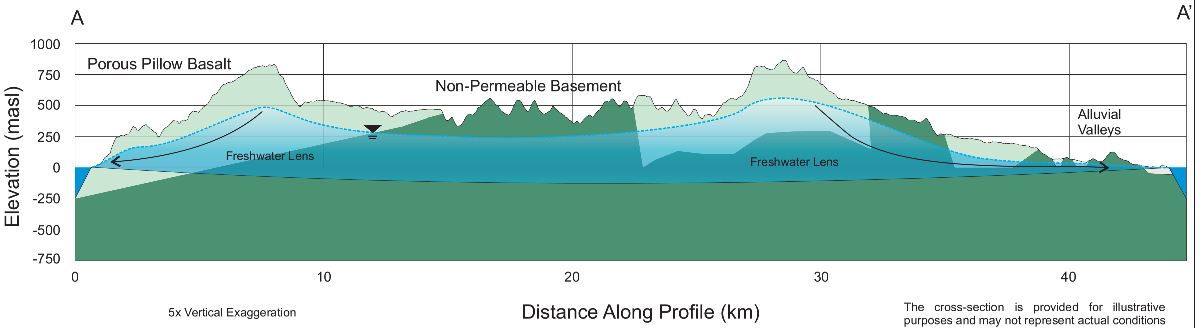
Sedimentary
- Coarse Alluvium
- Carbonate
- Karstic Carbonate
- Shale
- Sandstone

Igneous
- Unfractured Igneous (Undif.)
- f Fractured Igneous (Undif.)
- Permeable Volcanic

Metamorphic
- Unfractured Metamorphic (Undif.)
- f Fractured Metamorphic (Undif.)

- ★ Major City
- Groundwater Table
- ← Flow Line
- 🟥 Dominant Aquifer

CONCEPTUAL HYDROGEOLOGICAL CROSS-SECTION



The cross-section is provided for illustrative purposes and may not represent actual conditions

JAMAICA ISLAND - JAMAICA

LAT: 18.1824°N LONG: 77.3218 °W

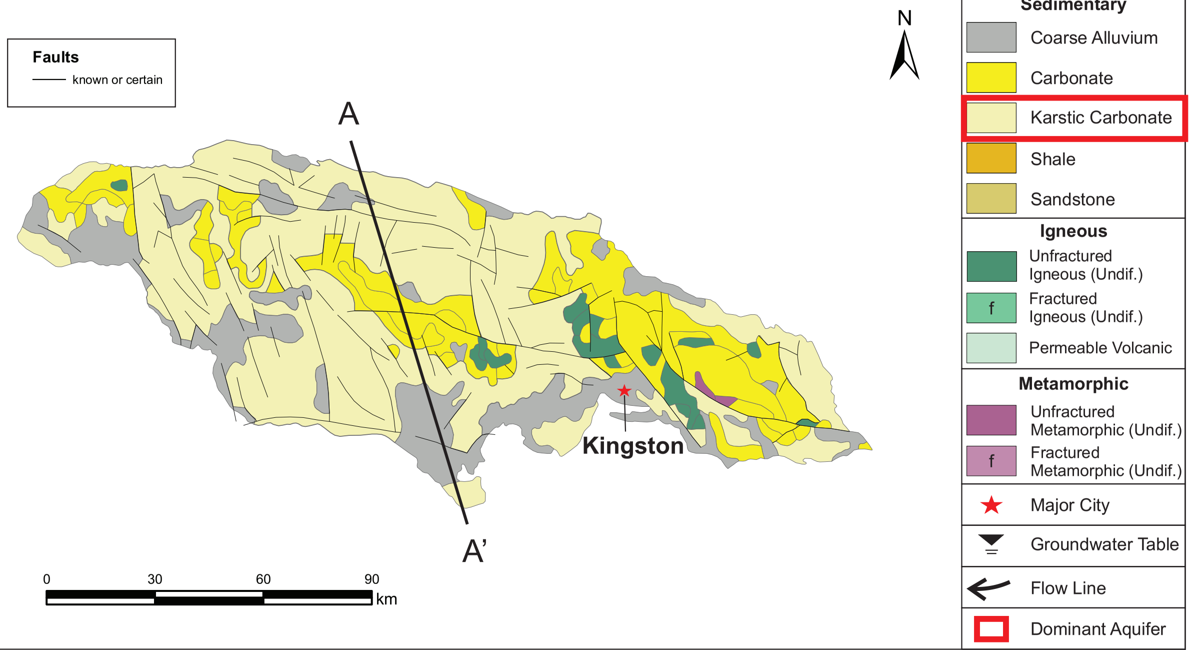
ISLAND STATISTICS

Area (km^2)	10991
Max. Elevation (masl)	2249
Aquifer Lithology	Karst Limestone
Average Annual Precipitation (mm/a)	2007
Calculated AET (mm/a)	883
Recharge (mm/a)	909
Max. Aquifer Thickness (m)	300
Groundwater Vol. (x10^9 m^3)	330
GW Vol. Abstracted (x10^6 m^3/a)	802.4
Predominant Natural Groundwater Quality	Fresh

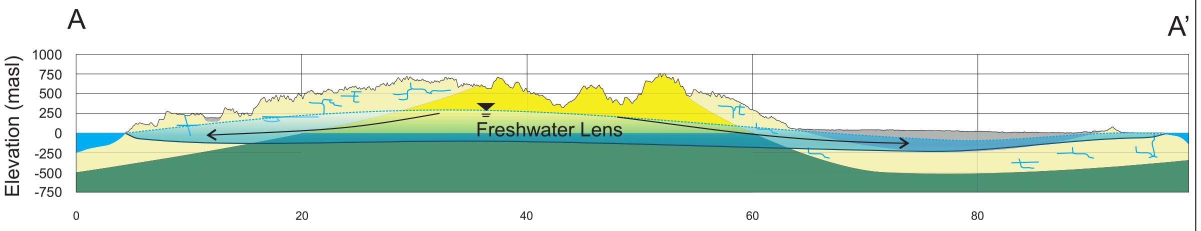
REF: DEM: USGS(2004), Shuttle Radar Topography Mission

GEO: U.S. Geological Survey Open-File. Report 97-470-K (2004)

GEOLOGICAL MAP



CONCEPTUAL HYDROGEOLOGICAL CROSS-SECTION



7x Vertical Exaggeration

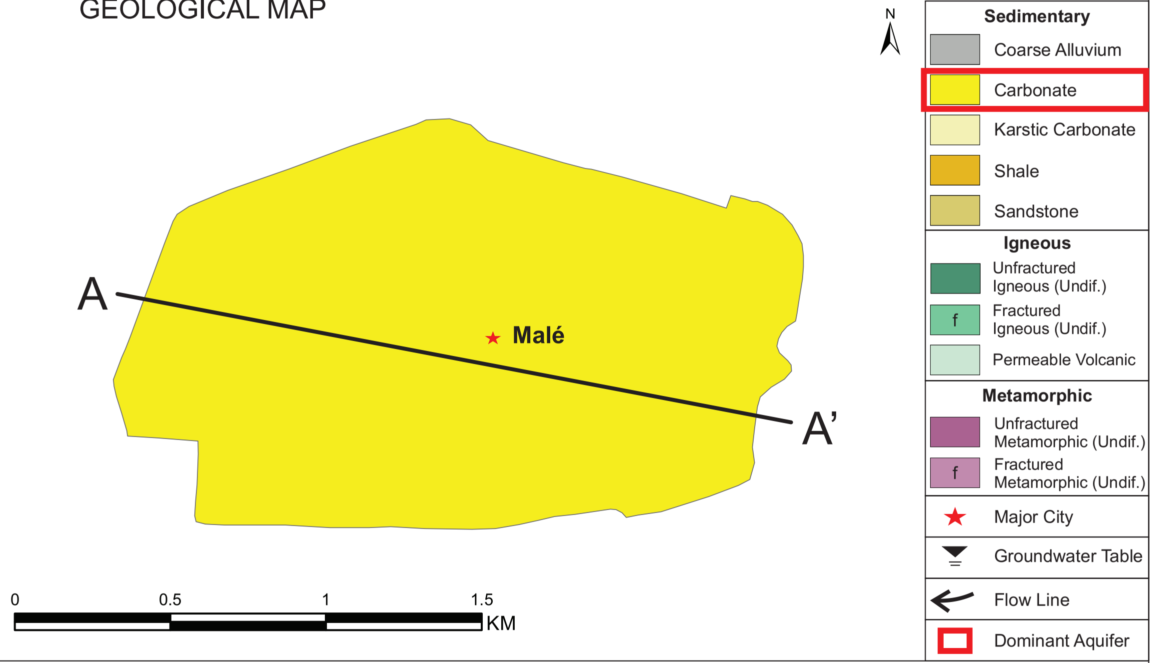
Distance Along Profile (km)

The cross-section is provided for illustrative purposes and may not represent actual conditions

MALÉ ISLAND - MALDIVES

LAT: 3.2000°N LONG: 73.2200 °E

GEOLOGICAL MAP

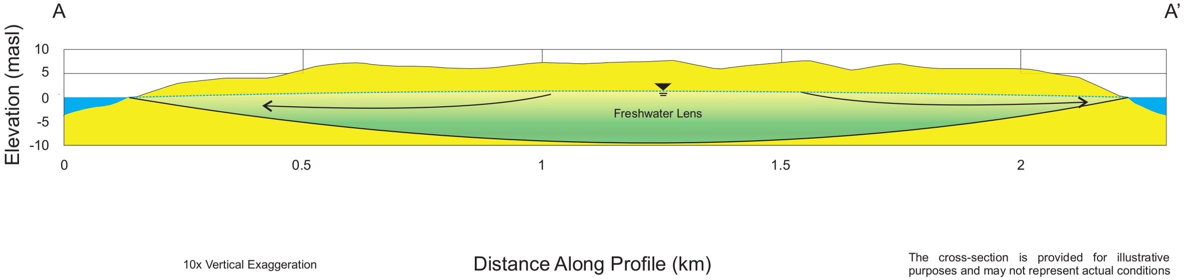


ISLAND STATISTICS

Area (km^2)	2
Max. Elevation (masl)	2.4
Aquifer Lithology	Coral Limestone
Average Annual Precipitation (mm/a)	2087
Calculated AET (mm/a)	1514
Recharge (mm/a)	573
Max. Aquifer Thickness (m)	2.7
Groundwater Vol. (x10^9 m^3)	0.003
GW Vol. Abstracted (x10^6 m^3/a)	5.9
Predominant Natural Groundwater Quality	Fresh

REF: DEM: USGS (2004), Shuttle Radar Topography Mission

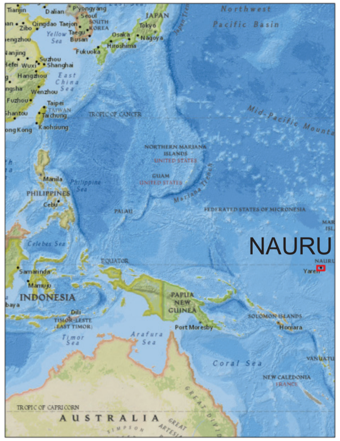
CONCEPTUAL HYDROGEOLOGICAL CROSS-SECTION



The cross-section is provided for illustrative purposes and may not represent actual conditions

NAURU ISLAND - NAURU

LAT: 0.5333°S LONG: 166.9333 °W

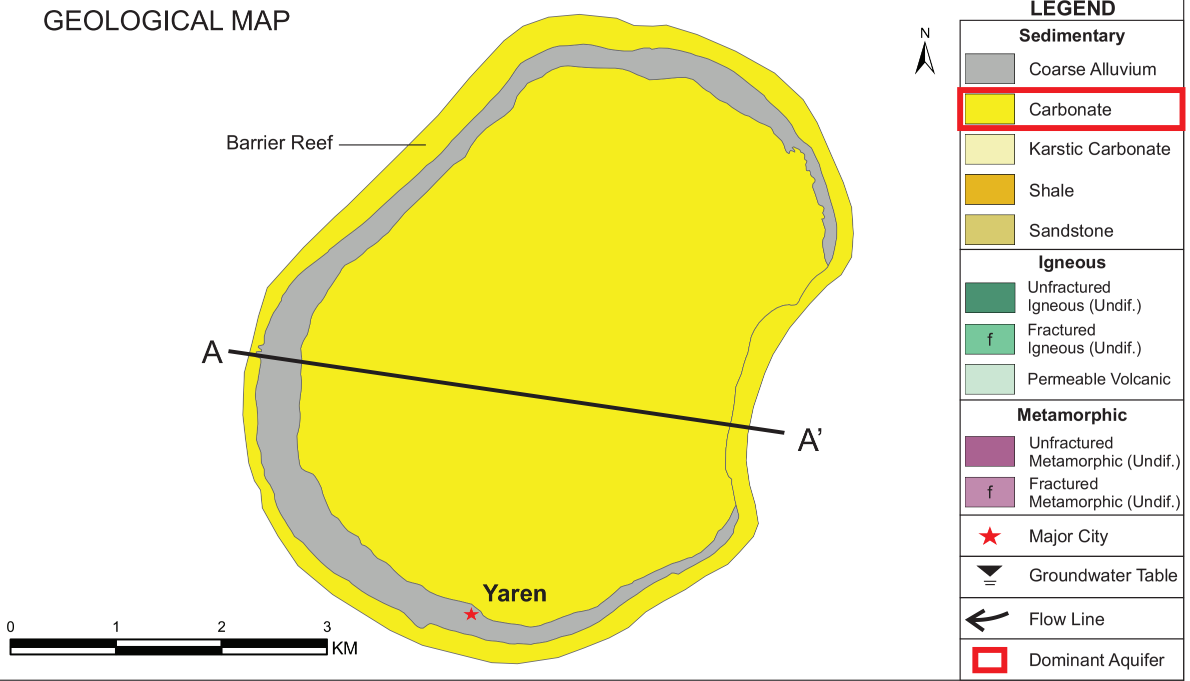


ISLAND STATISTICS

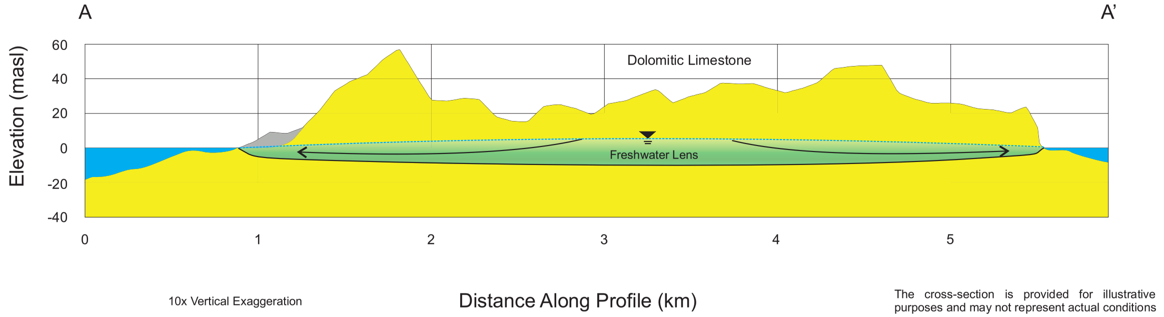
Area (km^2)	21
Max. Elevation (masl)	65
Aquifer Lithology	Limestone
Average Annual Precipitation (mm/a)	2373
Calculated AET (mm/a)	1186
Recharge (mm/a)	1186
Max. Aquifer Thickness (m)	5
Groundwater Vol. (x10^9 m^3)	0.55
GW Vol. Abstracted (x10^6 m^3/a)	0.11
Predominant Natural Groundwater Quality	Fresh

REF: DEM: USGS(2004), Shuttle Radar Topography Mission
GEO: Hill, P. J., and Jacobson, G. (2007) Structure and evolution of Nauru Island, central Pacific Ocean. Australian Journal of Earth Sciences. (Modified).

GEOLOGICAL MAP



CONCEPTUAL HYDROGEOLOGICAL CROSS-SECTION



The cross-section is provided for illustrative purposes and may not represent actual conditions

GRANDE TERRE ISLAND - NEW CALEDONIA

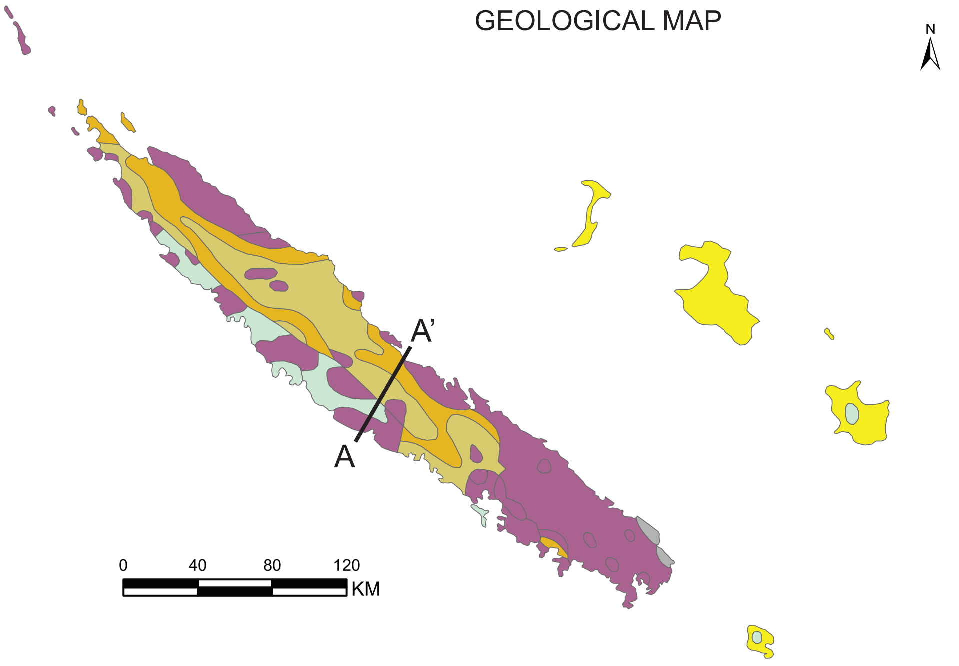
LAT: 21.2500°S LONG: 165.3000°W

ISLAND STATISTICS

Area (km^2)	16372
Max. Elevation (masl)	1628
Aquifer Lithology	Mixed
Average Annual Precipitation (mm/a)	1519
Calculated AET (mm/a)	1142
Recharge (mm/a)	374
Max. Aquifer Thickness (m)	75
Groundwater Vol. (x10^9 m^3)	61.4
GW Vol. Abstracted (x10^6 m^3/a)	0.455
Predominant Natural Groundwater Quality	Fresh

REF: DEM: USGS (2004), Shuttle Radar Topography Mission
GEO: U.S. Geological Survey Open-File. Report 97-470-K (2004)

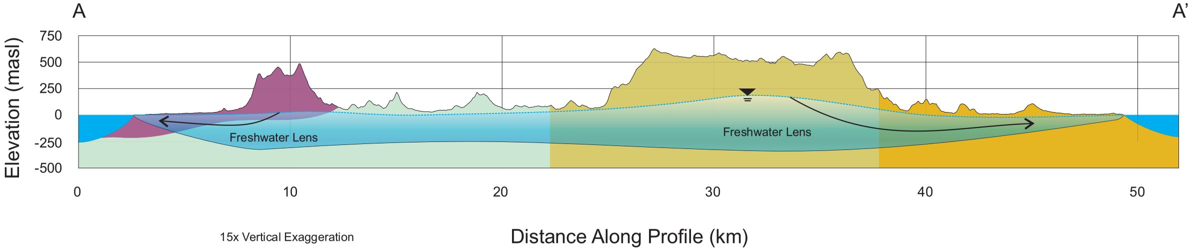
GEOLOGICAL MAP



LEGEND

Sedimentary	
▨	Coarse Alluvium
▨	Carbonate
▨	Karstic Carbonate
▨	Shale
▨	Sandstone
Igneous	
▨	Unfractured Igneous (Undif.)
f	Fractured Igneous (Undif.)
▨	Permeable Volcanic
Metamorphic	
▨	Unfractured Metamorphic (Undif.)
f	Fractured Metamorphic (Undif.)
★	Major City
▼	Groundwater Table
←	Flow Line
□	Dominant Aquifer

CONCEPTUAL HYDROGEOLOGICAL CROSS-SECTION



The cross-section is provided for illustrative purposes and may not represent actual conditions

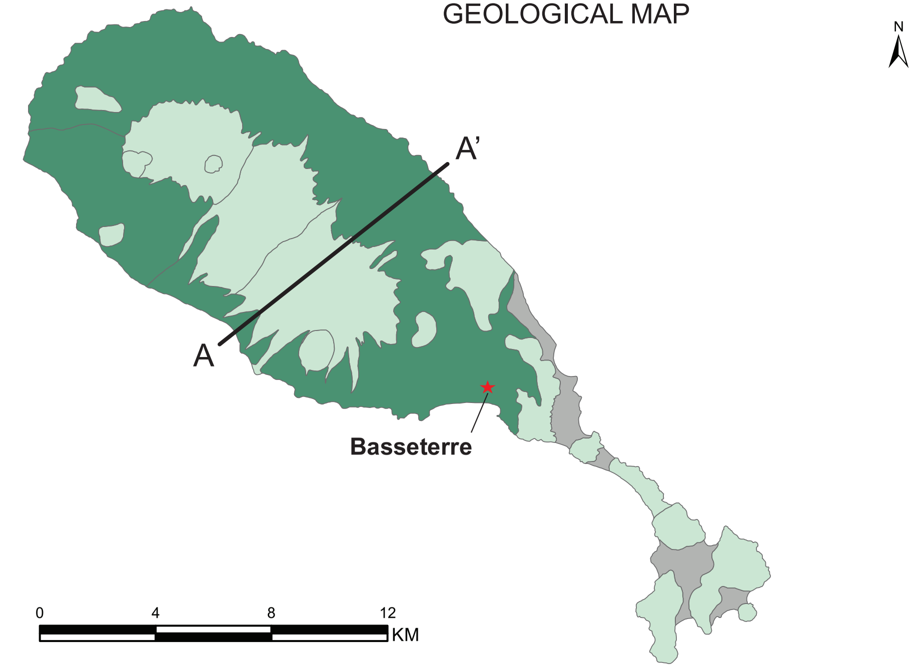
SAINT KITTS ISLAND - FEDERATION OF SAINT KITTS AND NEVIS

LAT:17.3000°N LONG: 62.7333°W

ISLAND STATISTICS

Area (km^2)	176
Max. Elevation (masl)	1156
Aquifer Lithology	Volcanic
Average Annual Precipitation (mm/a)	2165
Calculated AET (mm/a)	1346
Recharge (mm/a)	766
Max. Aquifer Thickness (m)	300
Groundwater Vol. (x10^9 m^3)	5.28
GW Vol. Abstracted (x10^6 m^3/a)	20
Predominant Natural Groundwater Quality	Fresh

GEOLOGICAL MAP



LEGEND

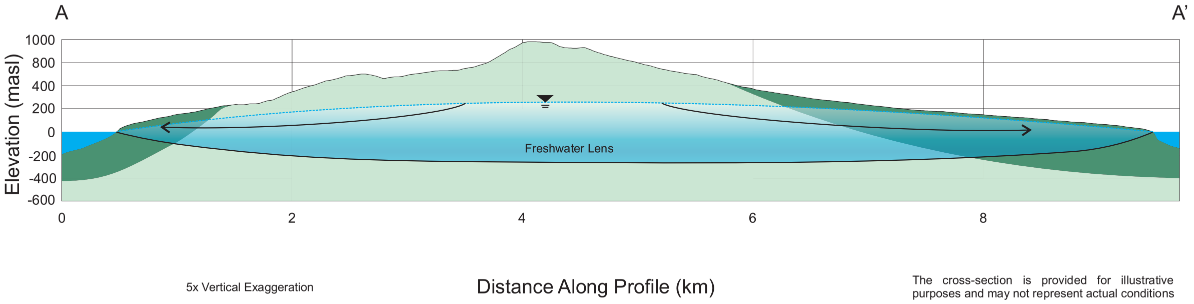
Sedimentary
- Coarse Alluvium
- Carbonate
- Karstic Carbonate
- Shale
- Sandstone

Igneous
- Unfractured Igneous (Undif.)
- f Fractured Igneous (Undif.)
- Permeable Volcanic

Metamorphic
- Unfractured Metamorphic (Undif.)
- f Fractured Metamorphic (Undif.)

- ★ Major City
- Groundwater Table
- Flow Line
- Dominant Aquifer

CONCEPTUAL HYDROGEOLOGICAL CROSS-SECTION



The cross-section is provided for illustrative purposes and may not represent actual conditions

REF: DEM: USGS (2004), Shuttle Radar Topography Mission
GEO: Roobol, J. M. and Smith, A. L. Geological Map of St. Kitts, West Indies.

The water systems of the world – aquifers, lakes, rivers, Large Marine Ecosystems (LMEs), and the open ocean – sustain the biosphere and underpin the health and socioeconomic wellbeing of the world's population. Many of these systems are shared by two or more nations. The transboundary waters, which stretch over 71% of the planet's surface, in addition to the transboundary subsurface aquifers, and the water systems entirely within the boundaries of the individual countries, comprise humanity's water heritage.

Recognizing the value of transboundary water systems, and the reality that many of them continue to be overexploited and degraded, and managed in fragmented ways, the Global Environment Facility (GEF) initiated the Transboundary Waters Assessment Programme (TWAP) Full Size Project in 2012. The Programme aims to provide a baseline assessment to identify and evaluate changes in these water systems caused by human activities and natural processes, as well as the possible consequences of these changes for the human populations that depend on them. The institutional partnerships forged in this assessment are expected to seed future transboundary assessments.

The final results of the GEF TWAP are presented in six volumes:

Volume 1 – ***Transboundary Aquifers and Groundwater Systems of Small Island Developing States: Status and Trends***
Volume 2 – ***Transboundary Lakes and Reservoirs: Status and Trends***
Volume 3 – ***Transboundary River Basins: Status and Trends***
Volume 4 – ***Large Marine Ecosystems: Status and Trends***
Volume 5 – ***The Open Ocean: Status and Trends***
Volume 6 – ***Transboundary Water Systems: Crosscutting Status and Trends***

Prepared by the UNESCO International Hydrological Programme under the framework of the Transboundary Waters Assessment Programme (TWAP), this document – Volume 1 – presents the first comprehensive indicator-based global assessment of status and trends in 199 transboundary aquifers and 42 groundwater systems of Small Island Developing States. Groundwater is a strategic resource for livelihoods and economic activities, and transboundary or insular conditions add complexity to the challenges of sustainable groundwater management.

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ISBN: 978-92-807-3531-4