

# Transboundary Aquifers and Groundwater Systems of Small Island Developing States

*Status and Trends*

**SUMMARY FOR POLICY MAKERS**



**VOLUME 1: GROUNDWATER**

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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.

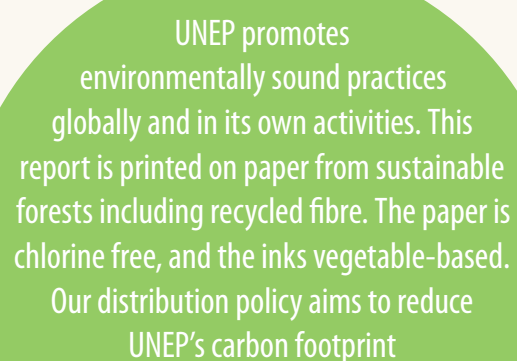
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# Summary for Policy Makers

The *Groundwater Component of the Transboundary Waters Assessment Programme (TWAP)* deals with Transboundary Aquifers (TBAs) and with Groundwater Systems of Small Island Developing States (SIDS). It was executed by the UNESCO International Hydrological Programme (IHP) and represents the first structured baseline assessment of the state of 199 transboundary aquifers and 42 SIDS groundwater systems as a basis for periodic assessments and to develop scenarios of possible future developments.

## *Transboundary Aquifers and Groundwater in SIDS: main challenges*

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 intensively in many regions of the world, and in a number of cases represents the only freshwater available for human uses. **Without proper knowledge and management, this vast resource can be rapidly and irreversibly degraded.** Pollution of aquifers is difficult to reverse; over-exploitation may have permanent impacts on aquifer behaviour and groundwater dependent systems. Groundwater cuts across basins and landscapes, sustaining ecosystems and biodiversity, mitigating the impacts of climatic **variability**, and making vital contributions to human health and social-economic development.

Unlike all other water bodies, aquifers are located in the subsurface and visible only through the eyes of science – hydrogeology. As a consequence, **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 by countries as shared resources.

This lack of recognition increases their vulnerability to anthropogenic pressures. **Therefore, there is a need for a systematic effort to identify and delineate aquifers that are transboundary (Inventory) and to provide a standardized description of their main characteristics** in terms of hydrogeology, environmental role and implications, socio-economic value and governance structure (Characterization).

**‘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;

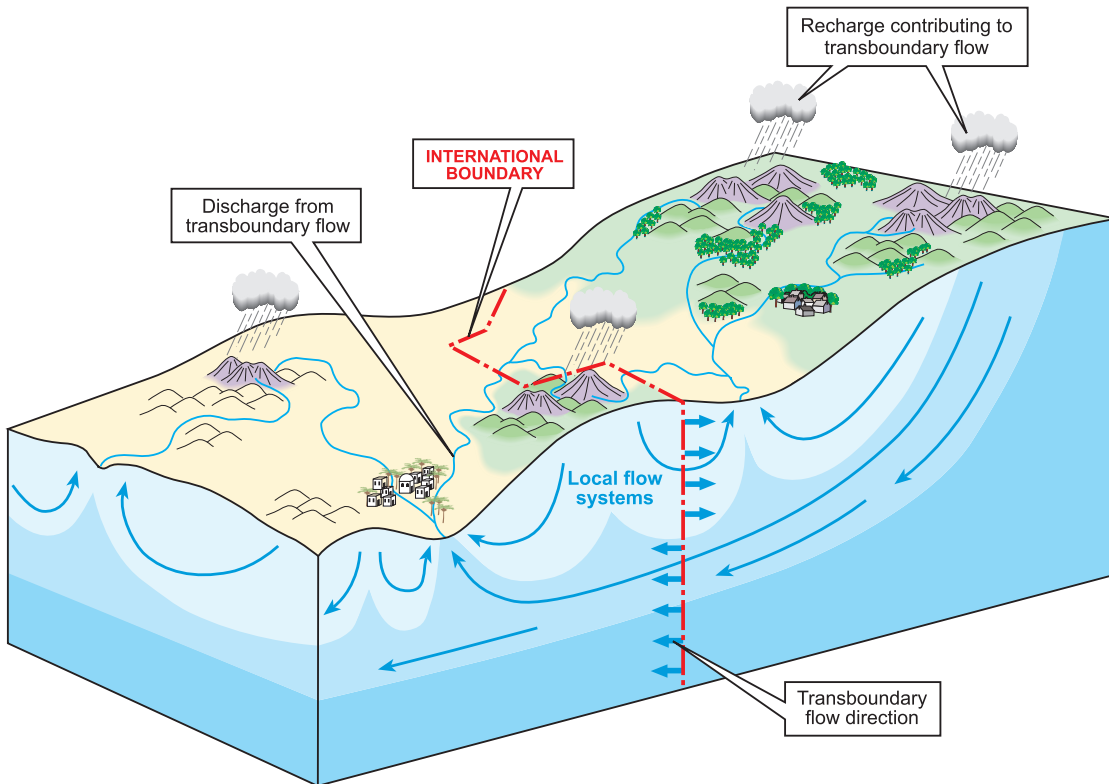
**‘Aquifer system’** means a series of two or more aquifers that are hydraulically connected;

**‘Transboundary aquifer’** and **‘transboundary aquifer system’** mean, respectively, an aquifer or aquifer system, parts of which are situated in different States;

Definitions from the UNGA Resolution 63/124 on the “Law of Transboundary Aquifers” and the draft articles contained therein, 2008.



Schematic diagram of a transboundary aquifer system (modified from Puri et al., 2001)



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## Objectives of TWAP Groundwater Component

The overall goals of the Groundwater component of TWAP, executed by UNESCO-IHP, are to:

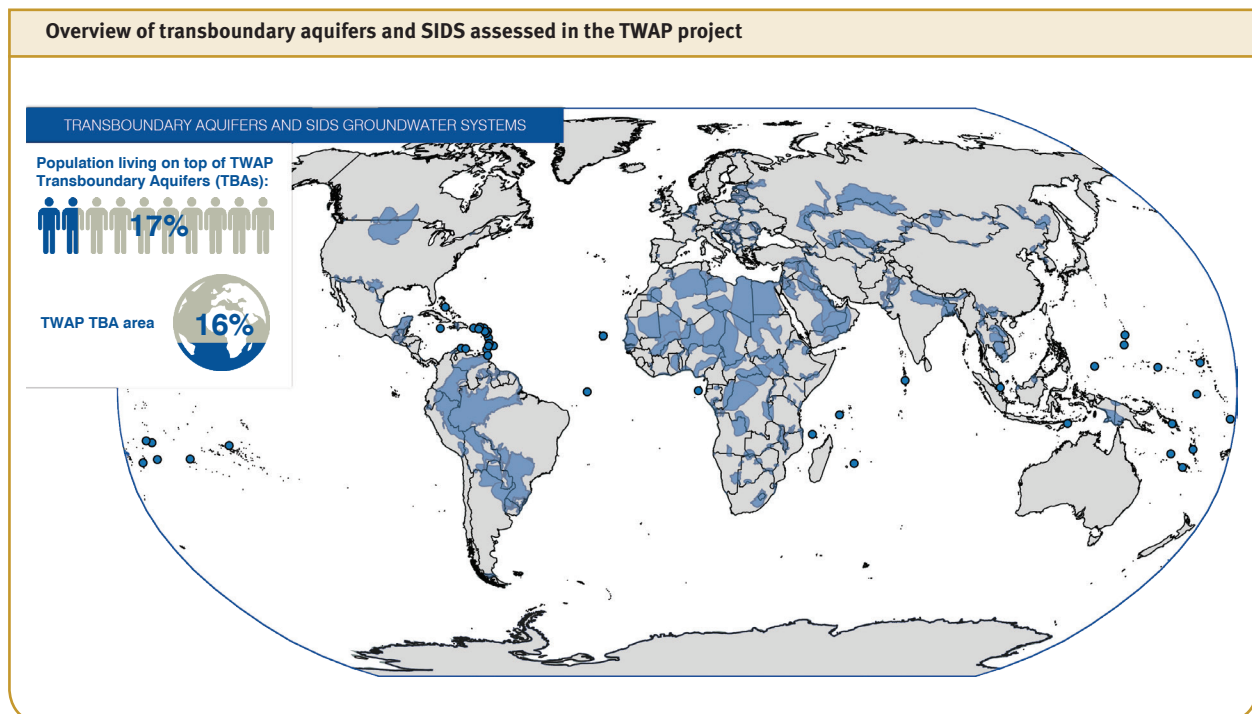
- (1) Provide a description of the present conditions of main transboundary aquifers (TBAs with areal extent > 5,000 km<sup>2</sup>, and a few selected smaller ones) and aquifers in Small Island Developing States (SIDS), which will enable the determination of priority aquifers/regions for investments;
- (2) Bring to the global attention the major issues, concerns and hotspots associated with these transboundary aquifer systems and SIDS aquifers, and to catalyse action.

TWAP in Numbers	
<b>199</b> including	Aquifers in the Global Inventory
<b>91</b>	Aquifers for WaterGAP modeling (TBAs > 20,000 km <sup>2</sup> )
<b>126</b>	Inland Countries
<b>42</b>	Small Islands Developing States
<b>502</b>	Transboundary Aquifers-Country Segments
<b>&gt;200</b>	Experts from 76 countries consulted (for TBAs)

The results of the TWAP Groundwater assessment provide elements to help 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, degradation, etc.)?**
- (ii) **Where will all these problems be occurring?**
- (iii) **How will water conditions and uses evolve over the coming decades?**
- (iv) **Which international groundwater systems are likely to prevent, buffer or mitigate water-related problems under increasing stresses during the coming decades?**

This document presents the key messages, approach and selected results first for the Transboundary Aquifers and then for the Groundwater Systems of Small Island Developing States.



## Transboundary Aquifers: Key messages

1. Prior to TWAP, the UNESCO Internationally Shared Aquifer Resources Management (ISARM) Programme identified 166 transboundary aquifers larger than 5,000 km<sup>2</sup>, and some of these aquifers' locations and/or boundaries were not known. **The TWAP project improved this inventory, which now consists of 199 transboundary aquifers having surface expression of more than 5,000 km<sup>2</sup>, or of significant regional importance, with greatly improved accuracy in their location and delineation.**
2. Worldwide, the majority of transboundary aquifers with surface expression greater than 5,000 km<sup>2</sup> are located outside regions highly affected by groundwater development stress. Indeed, transboundary aquifers experience low depletion rates (< 2 mm / year) in most regions. Human dependence on transboundary groundwater is also generally low to very low in most cases. **The still largely untapped groundwater resources contained in transboundary aquifers have a role in preventing, buffering or mitigating impacts of global change on human livelihoods and the environment.**
3. **Areas of high groundwater development stress are presently limited but are likely to more than double between now and 2050.** The number of national segments of transboundary aquifers showing high groundwater stress (> 20 per cent) is expected to increase between now and 2050 from 20 to 58.
4. **New hotspots, mainly driven by population pressures, are projected to develop in a number of national country segments.** These are located mainly in Sub-Saharan Africa, China and Mexico. Country segments located the Middle East, North Africa region, South Asia, or countries like Uzbekistan and Botswana are also of concern. 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.
5. Despite the general lack of information on anthropogenic pollution in transboundary aquifers, it can be said that all transboundary aquifers characterized by very low groundwater quality are: 1) highly impacted by irrigation return flows, 2) located in densely populated areas, and 3) with low to medium natural recharge, such as the Nubian, Indus, and Pre-Caspian transboundary aquifers.
6. **Regarding governance and institutional frameworks for transboundary aquifers, international agreements are absent, with few albeit notable exceptions.** In 2016, there are six transboundary aquifers with specific agreements and two aquifers with informal agreements. 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, and equitable access to benefits from water and conservation of ecosystems.
7. **The assessment has also provided evidence of considerable gaps in publicly available information on transboundary aquifers and modern data on groundwater in general.** Local knowledge harnessed through the regional expert networks is highly valuable and for some aspects critical, but far from providing a globally complete picture of the situation. Despite modelling limitations, it is a fact that without the help of modelling this assessment would not have been possible. It is also apparent that knowledge on deep groundwater resources is lacking in many regions. An additional issue is that information on groundwater dependent ecosystems is minimal.

## Groundwater Systems of Small Island Developing States (SIDS): Key messages

SIDS face common challenges: 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.

The TWAP assessment covers 42 SIDS. These are the ones included in the UN-DESA<sup>1</sup> list which have a maximum size of 50,000 km<sup>2</sup>, do not have part of their territory located on the continent, and do not exceed 5 million inhabitants.

1. Groundwater sustainability in the SIDS is in many cases inextricably linked to human and ecosystem health. **Population density appears to be the main driver of water stress, with values ranging from medium to very high in all but one of the islands assessed in this study.**
2. **A large number of islands (71 per cent) are at risk of water scarcity** (medium to very low value of renewable groundwater per capita), 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.
3. **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.** The marked difference among regions probably reflects differences in the availability of alternative water resources, either surface water or seawater desalination, and/or different stages of socio-economic development.
4. 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.**
5. 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.**
6. 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.

71%

SIDS are at risk of water scarcity for low-lying 91% islands

73%

SIDS are at risk from groundwater pollution often worsened by seawater intrusion and salinization

10%

of Caribbean and Atlantic/Indian Ocean SIDS

72%

of Pacific SIDS experience high human groundwater dependence

<sup>1</sup> United Nations Department of Economic and Social Affairs. For the list of SIDS defined by UNESCO, see <http://www.unesco.org/new/en/natural-sciences/priority-areas/sids/about-unesco-and-sids/sids-list/>

## Global assessment of transboundary aquifers: status and trends

### An indicator-based approach

The indicators are the building blocks of the TWAP assessment. They capture the state and trends of the world’s groundwater resources. They provide a basis for the answers to questions such as “Where will water conditions hotspots develop?” and also facilitate comparisons between transboundary aquifers, on standardized parameters (quantity, quality, etc.), in order to set priorities for interventions. Out of twenty indicators that have been formulated, ten indicators have been selected as core indicators, classified in four thematic clusters. Four core indicators have been also calculated for future conditions (2030 and 2050).

Thematic cluster	Core Indicators	Current	Future
Quantity cluster	Groundwater Recharge	✓	
	Groundwater Depletion	✓	
Quality cluster	Groundwater natural background quality	✓	
	Groundwater pollution	✓	
Socio-economic cluster	Population density	✓	✓
	Renewable groundwater per capita	✓	✓
	Human dependence on groundwater	✓	✓
	Groundwater development stress	✓	✓
Governance cluster	Transboundary legal framework	✓	
	Transboundary institutional framework	✓	

### Data sources

**A Global Inventory established on the basis of a questionnaire sent to a network of more than 200 national experts.** The data collected include a map of the boundaries of the transboundary aquifer, an indicative cross-section, and values for the core and additional current indicators. **Regional workshops** with national experts were held to discuss these data.

**Modelling current and future state (2030 and 2050) for Transboundary Aquifers > 20,000 km<sup>2</sup>**: the University of Frankfurt was commissioned by UNESCO-IHP to apply the WaterGAP model (Döll et al., 2014).



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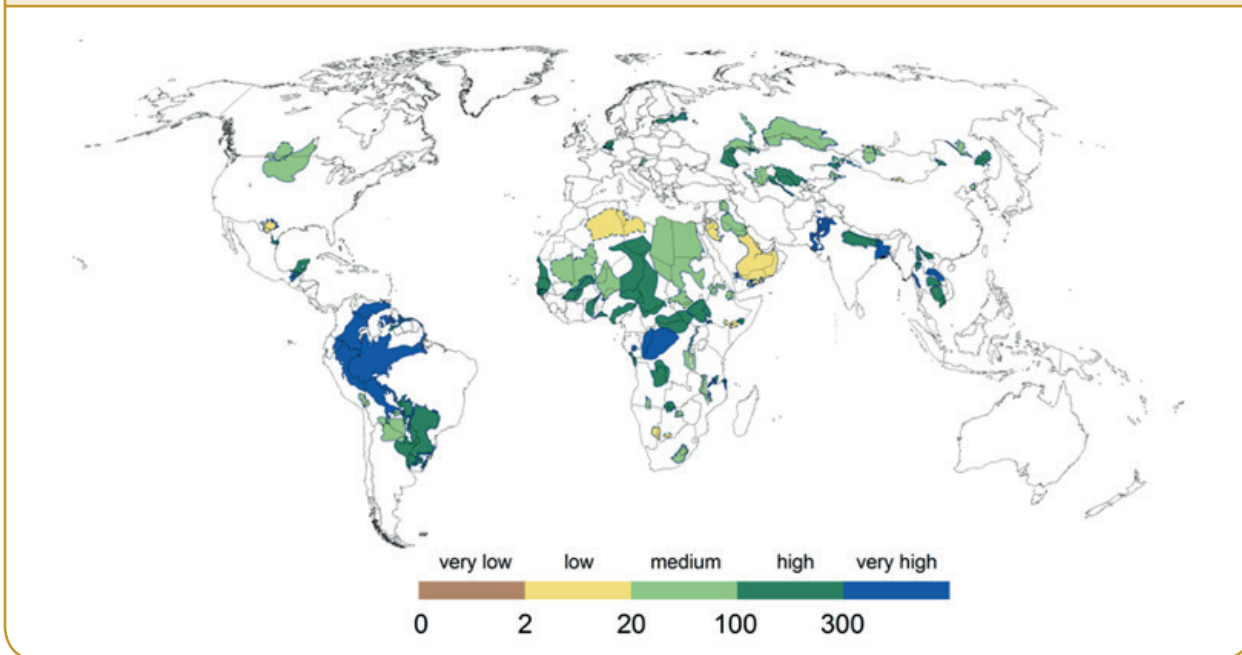


## Selected results by thematic group

### Quantity Cluster - Groundwater Recharge

**Mean annual groundwater recharge including artificial recharge from irrigation per transboundary aquifer (in mm/yr)**

Highest groundwater recharge rates exceeding 300 mm/yr are found in humid areas including the Amazonas aquifer, the Cuvette aquifer in Central Africa, or the Indus River Plain aquifer. Transboundary aquifers characterized by low recharge rates between 2 and 20 mm/yr are the Northwest Sahara Aquifer System and the two aquifers located on the Arabian Peninsula. No transboundary aquifers were identified with very low groundwater recharge rates below 2 mm/yr.



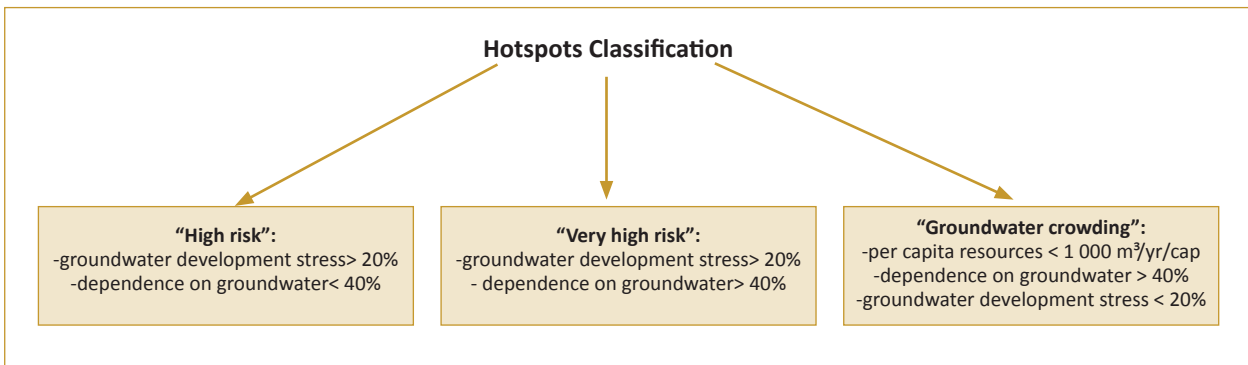
### Quality Cluster

Data for calculating the values of the two indicators of the quality cluster are scarce – available only for 125 country segments, including 5 complete transboundary aquifers – and do not allow any global-scale consideration. However, it can be noted that transboundary aquifers with very low quality (< 20 per cent of the aquifer area) are transboundary aquifers that are highly impacted by irrigation return flows, located in densely populated areas, and with low to medium natural recharge, for example the Nubian, Indus, and Pre-Caspian transboundary aquifers.



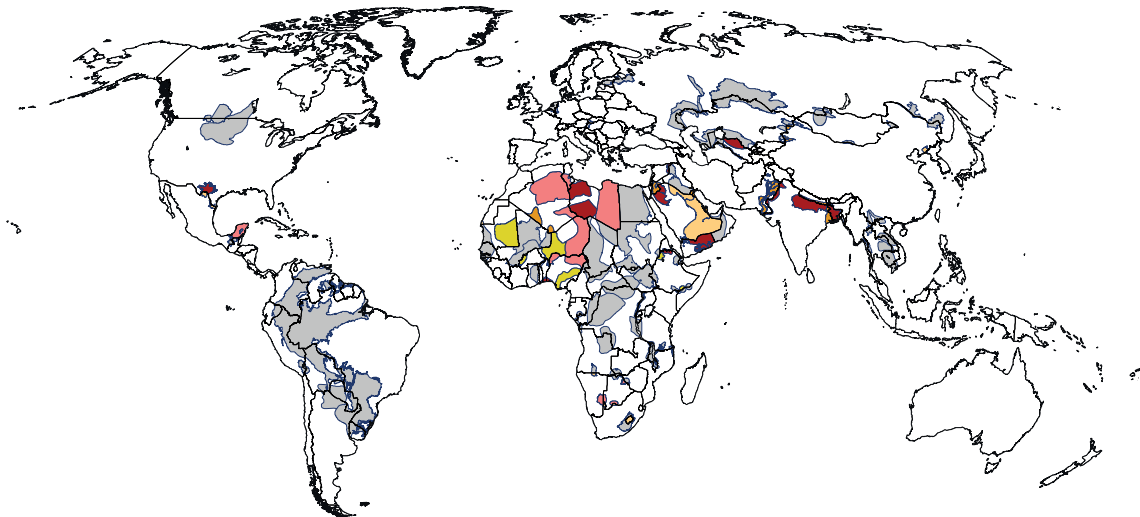
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### Socio-Economic Cluster: Hotspots under current and future conditions



#### Hotspots under current and future conditions

In total, 68 out of 258 TBA-country segments extending over 36 TBAs are presented as current and/or future hotspots. Two-thirds of the identified hotspots are located on the African continent and the Arabian Peninsula but segments classified in “very high risk” category are also distributed over Asia and America.



#### Hotspots under current and future conditions

- Very high risk (16 country segments)
- High risk (11 country segments)

#### Hotspots under future conditions only

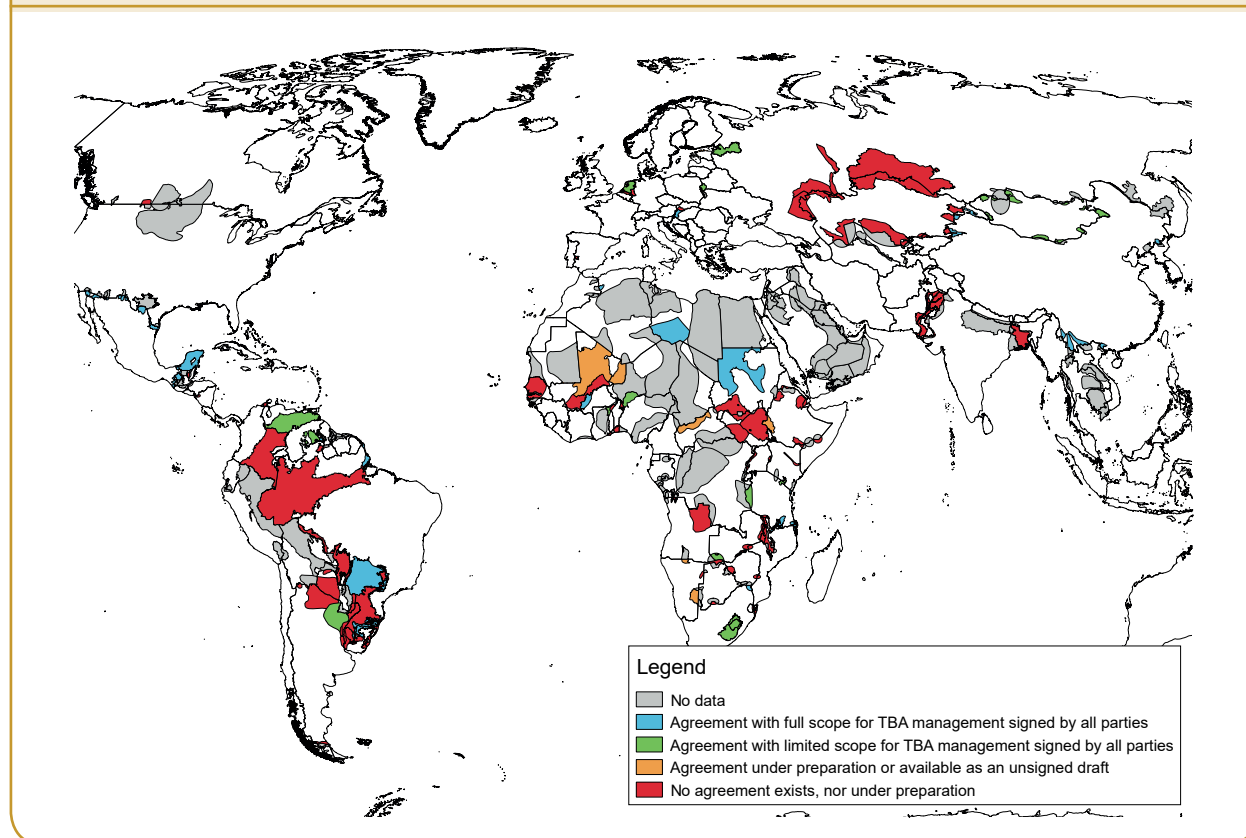
- Very high risk (15 country segments)
- High risk (16 country segments)
- Groundwater crowding (8 country segments)

*Having a country segments identified as hotspot implies challenges for the entire associated aquifer. 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).*

Future 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 (up to 40 percentage points), are projected for transboundary aquifers country segments located in Botswana, the Middle East and North Africa region, South Asia, Uzbekistan, and Yucatán. Eight new country segments were identified as potential hotspots of “groundwater crowding”, all of them in West or East Africa.

## Governance Cluster: Transboundary legal framework

**Transboundary legal framework per TBA country segments.** In many cases, the data from countries sharing an aquifer are not consistent among all countries. This includes transboundary aquifers that are known to have agreements (e.g. the Guaraní Aquifer System, North-western Sahara Aquifer System, Nubian Sandstone Aquifer System and Illumedden Aquifer System). An explanation may lie in the fact that an agreement may not have yet been ratified in all countries involved, and experts may interpret agreements differently, resulting in variations in the answers provided by the different countries sharing the aquifer.



Only a handful of specific agreements on transboundary aquifers exist. Worldwide, in 2016, there are six transboundary aquifers with specific agreements and two aquifers with informal agreements. 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 63/124 (2008) on the Law of Transboundary Aquifers by a transboundary aquifer 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 transboundary aquifers, 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 transboundary aquifer agreement and organization that set out the obligation to cooperate and the relevant terms of engagement among the concerned States.

*The "WaterGAP Groundwater Modeling Report" is available at TWAP database on the UNESCO ISARM website: [www.twap.isarm.org](http://www.twap.isarm.org). All transboundary aquifer sheets are available at the UNESCO International Groundwater Resources Assessment Centre (IGRAC) data portal: <http://twapviewer.un-igrac.org>.*

# Global assessment of Groundwater Systems of Small Island Developing States (SIDS)

## Selection of the SIDS / islands included in the assessment

Three criteria have been chosen to select the 42 SIDS to be included in the assessment.

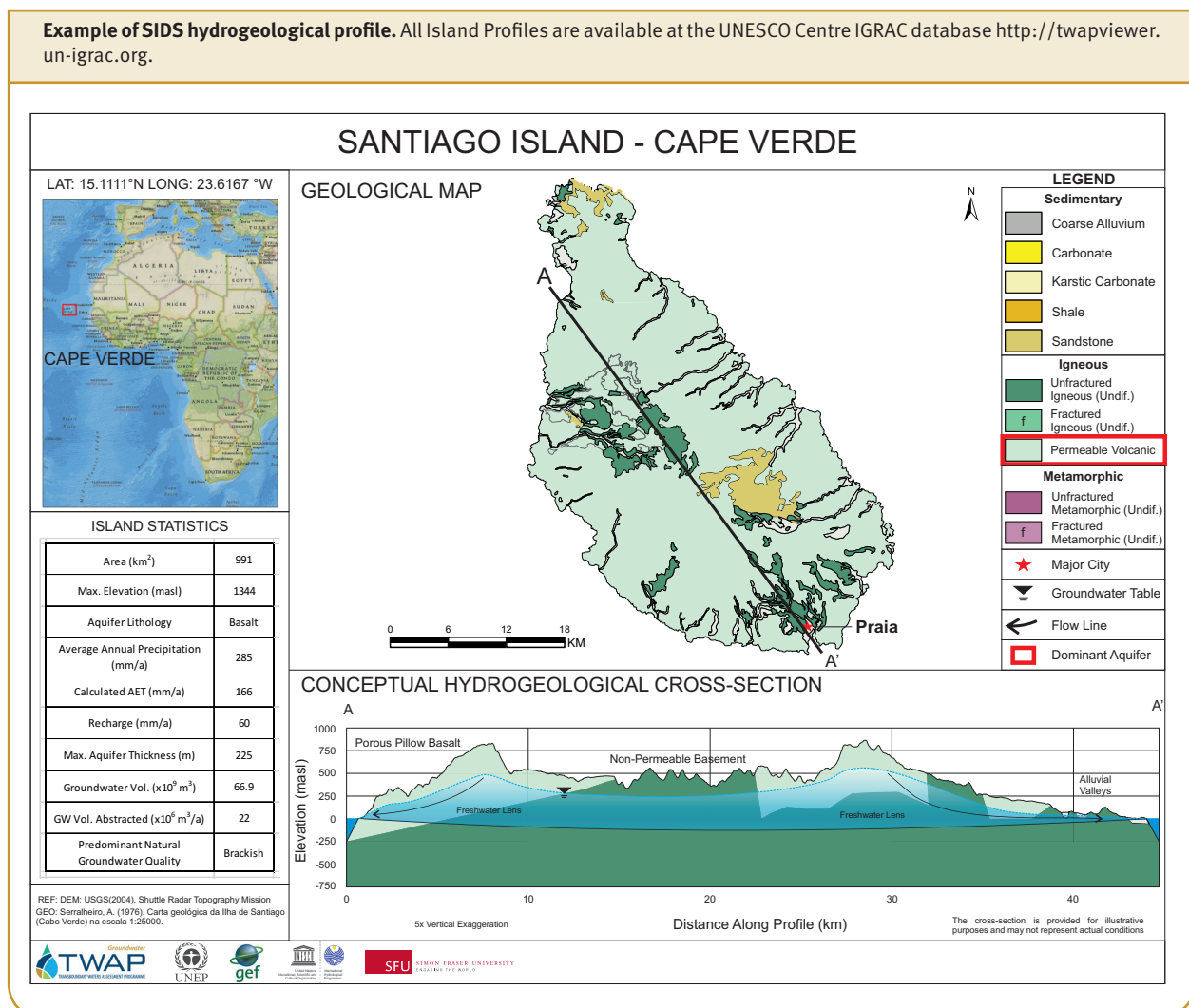
1. A maximum size of 50,000 km<sup>2</sup>.
2. The State should consist of one or more islands and not be located on a continent.
3. The number of inhabitants should not exceed 5 million.

One representative island within each SIDS has been selected. Typically, the representative island had the largest population.

## Data and indicators for the assessment of Groundwater Systems

- (i) Preliminary data collected from global and regional publications and existing and accessible databases. 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) Information provided by experts through questionnaires.

**Example of SIDS hydrogeological profile.** All Island Profiles are available at the UNESCO Centre IGRAC database <http://twapviewer.un-igrac.org>.



The hydrogeological characterization and the socio-economic and environmental data collected have allowed the establishment of 20 TWAP indicators, including the 10 core indicators (see p. 5) and an indicator for saltwater intrusion.

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 SIDS. Within the context of SIDS, it is crucial to consider the link between the aquifer and the ocean because of the potential for saltwater intrusion.

## Selected Results

### Island hydrogeological profiles (see Figure on p. 10)

For each SIDS, a representative hydrogeological profile was generated. This consists of a location map, a generalized geological map with the freshwater lens; and a representative cross-section, together with the relevant statistics. For the near-coast, the shape of the freshwater lens is approximated on the basis of questionnaire data, if provided. Thicker lenses are assumed to develop under high topography areas.

### Assessment of Risk Factors

Risk associated with availability of groundwater and pollution are of concern for all SIDS; low-lying SIDS are also particularly vulnerable to saltwater intrusion. These risks are particularly exacerbated when human groundwater dependence is high, as this is the case in many Pacific low-lying SIDS.

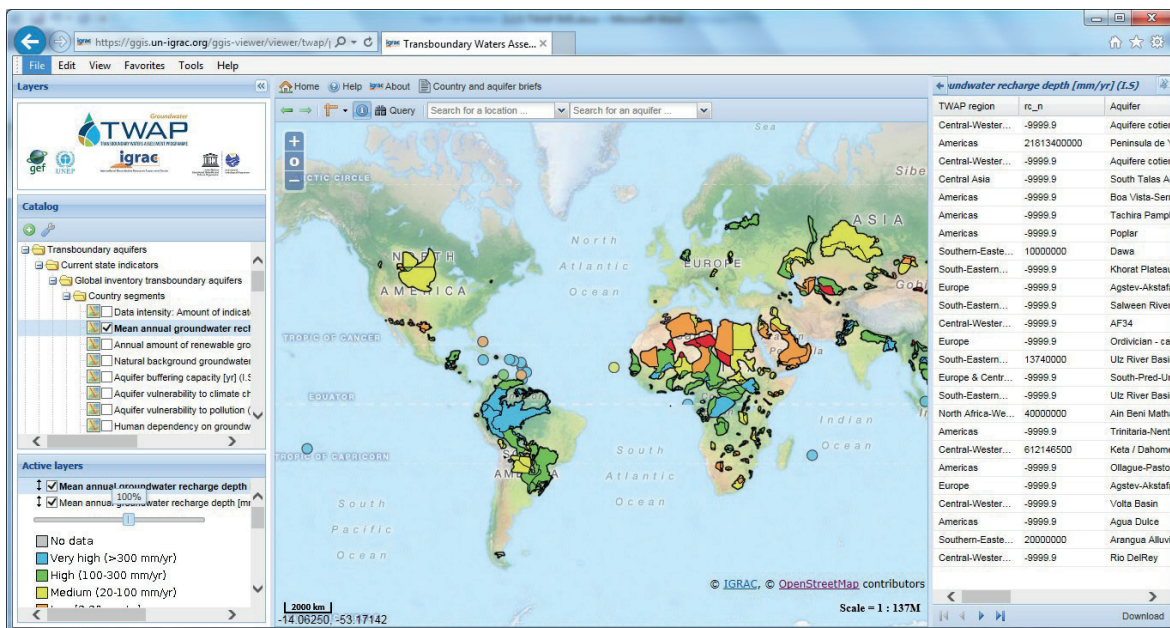
All data gathered as part of the assessment of groundwater systems in SIDS, including aquifer properties, values of time-dependent variables, and computed indicators, are available in the report “Assessment of SIDS Groundwater Systems” available at TWAP database on the UNESCO ISARM website: [www.twap.isarm.org](http://www.twap.isarm.org).

All hydrogeological profiles of the SIDS assessment are available at the UNESCO International Groundwater Resources Assessment Centre (IGRAC) data portal: <http://twapviewer.un-igrac.org>.

Assessment of Risk Factors distinguishing Mountainous SIDS and Low-Lying SIDS						
a: Recharge/Capita						
b: Nat. Water Quality						
c: Human GW Dependence						
d: Pollution						
e: Saltwater Intrusion						
f: Population Density						
	No data					
	Low to very Low					
	Medium					
	High to Very High					
<b>Mountainous SIDS</b>						
<b>Atlantic and Indian Ocean</b>						
Cape Verde						
Comoros						
Mauritius						
Sao Tome and Principe						
<b>Caribbean</b>						
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						
<b>Pacific</b>						
American Samoa						
Belau/Palau						
C'wealth of N. Marianas						
Cook Islands						
Fiji						
French Polynesia						
<b>Low-Lying SIDS</b>						
<b>Atlantic and Indian Ocean</b>						
Maldives						
Seychelles						
<b>Caribbean</b>						
Anguilla						
Aruba						
Barbados						
Netherland Antilles						
The Bahamas						
US Virgin islands						
<b>Pacific</b>						
Guam						
Kiribati						
Marshall Islands						
Nauru						
New Caledonia						
Tonga						
Tuvalu						

Online access to results: The TWAP Groundwater Information Management System

A dedicated web-based data portal has been established to provide access to all data in the TWAP groundwater database developed by UNESCO-IHP. The Information Management System (IMS) contains **aggregated data and indicators values collected during the project**, 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. Data can be displayed per country segment or for the whole transboundary aquifer, and overlays of different map layers can be made. The IMS provides also direct access to the transboundary aquifer and SIDS groundwater systems **Information Sheets**. The TWAP Groundwater IMS is publicly accessible via the UNESCO Centre IGRAC data portal: <http://twapviewer.un-igrac.org>



Example from TWAP Groundwater Information Management System <http://twapviewer.un-igrac.org>



## Acknowledgements

The assessment of Transboundary Aquifers and Groundwater Systems of Small Island Developing States has been undertaken by the UNESCO International Hydrological Programme (IHP) and the UNESCO International Groundwater Resources Assessment Center (IGRAC) in partnership with the Simon Fraser University (Canada) and Frankfurt Goethe University (Germany). This assessment has only been possible because of contributions of many partners worldwide and in particular those of national experts who provided indispensable data on the (transboundary) aquifer systems in their countries.

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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*

A *Summary for Policy Makers* accompanies each volume.

This document – Volume 1 – *Summary for Policy makers* highlights the findings of 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. This is particularly the case in the specific transboundary or insular situations.

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