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GRAPHIC

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GROUNDWATER AND CLIMATE CHANGE

Small Island Developing States (SIDS)

INTERNATIONAL HYDROLOGICAL PROGRAMME
Division of Water Sciences

Groundwater monitoring wells on Roi-Namur Island, Kwajalein Atoll, Republic of the Marshall Islands.

INTRODUCTION: GROUNDWATER, CLIMATE CHANGE, AND SMALL ISLAND DEVELOPING STATES (SIDS)

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SC-2015/WC/29

GRAPHIC
GLOBAL COMMITMENT TO GROUNDWATER AND CLIMATE CHANGE

The United Nations Educational, Scientific, and Cultural Organisation (UNESCO) International Hydrological Programme (IHP) initiated the Groundwater Resources Assessment under the Pressures of Humanity and Climate Change (GRAPHIC) project in 2004 to better understand the effects of climate change on global groundwater resources.

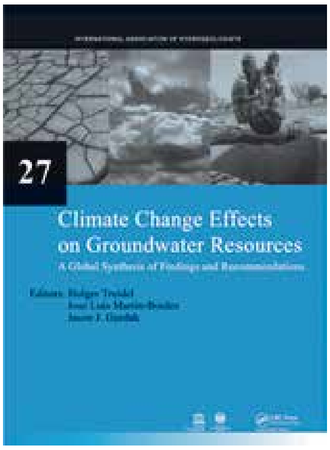
Vision of GRAPHIC:

- advance sustainable groundwater management considering projected climate change and linked human effects.

Mission of GRAPHIC:

- provide a platform for exchange of information through case studies, thematic working groups, scientific research, and communication.
- serve the global community through providing scientifically based and policy-relevant recommendations.
- use regional and global networks to improve the capacity to manage groundwater resources.

GRAPHIC improves understanding of how groundwater interacts within the global water cycle, supports ecosystems and humankind and, in turn, responds to complex and coupled pressures of human activities and climate change. To achieve these objectives within a global context, GRAPHIC is a collaborative effort and umbrella for international research, education, and outreach. GRAPHIC has international investigations covering major geographical regions, groundwater resource topics, and methods to help advance the combined knowledge needed to address scientific and social aspects of the global groundwater crisis in the context of climate change.



Climate Effects on Groundwater – A Global Synthesis of Findings and Recommendations is a compilation from 20 studies in more than 30 countries under GRAPHIC network.

GRAPHIC uses a multidisciplinary scientific approach that extends beyond physical, chemical, and biological investigations to include human systems of resource management and governmental policies. GRAPHIC has been divided into subjects, methods, and regions. The subjects encompass (i) groundwater quantity (recharge, discharge, and storage), (ii) quality, and (iii) management aspects. GRAPHIC uses many scientific methods, including analysis of field data, geophysics, geochemistry, paleohydrology, remote sensing, and modelling. GRAPHIC has regional studies in Africa, Asia and Oceania, Europe, Latin America, and the Caribbean and North America.

Additional information about GRAPHIC is available at **www.graphicnetwork.net**.

INTRODUCTION: GROUNDWATER, CLIMATE CHANGE, AND SMALL ISLAND DEVELOPING STATES (SIDS)

GROUNDWATER is an essential part of the hydrological cycle and is a valuable natural resource providing a primary source of water for agriculture, domestic, and industrial uses throughout the world. Nearly half of all drinking water in the world[1] and about 43% of all water effectively consumed in irrigation[2] is sourced from groundwater. Groundwater is vital for sustaining many streams, lakes, wetlands, and other dependent ecosystems[3]. However, global groundwater resources are in a state of crisis[4] because of over-abstraction in many semiarid and arid regions and the uncertain consequences of climate change[5].

CLIMATE CHANGE is expected to significantly modify the global hydrological cycle. There is a broad consensus that climate change effects will be felt by humans mainly through its impacts on water resources globally, including groundwater resources[6,7], and water-related disasters such as floods and droughts. Direct impacts of climate change on natural processes (groundwater discharge, recharge and storage and groundwater quality) may be exacerbated by the human response to these impacts, such as increased groundwater abstraction due to extended and more frequent droughts. The effects of climate change on groundwater resources are therefore closely linked to sustainable development goals and to global change drivers, including population growth, land use changes, and urbanization[8].

SMALL ISLAND DEVELOPING STATES (SIDS) are a group of 52 developing countries on low-lying carbonate and volcanic islands in the Pacific; Caribbean; and Africa, Indian Ocean and South China Sea that all share similar sustainable development challenges[9]. Although each are small in area, SIDS collectively have a population of 63.2 million people and a gross domestic product (GDP) of $575.3 billion (USD)[10].

Storm wave-induced overwash on Roi-Namur Island, Kwajalein Atoll, Republic of the Marshall Islands.

SIDS are among the most vulnerable human and natural systems because of their small size, remoteness, rapid population growth, restricted capacity and limited natural resources, and sensitivity to natural disasters (cyclones, hurricanes, earthquakes, volcanic eruptions) and climate variability and change. Economic challenges often include small domestic markets and heavy dependence on a few remote markets; high costs for energy, infrastructure, transportation, and communication; long distances from export markets and import resources; and a high volatility of economic growth[9].

The vulnerability of SIDS is directly affected by limited freshwater (groundwater and surface water) resources that are likely to be seriously compromised due to rising sea levels and climate variability and change. To bring attention to SIDS, the United Nations declared 2014 as the International Year of Small Island Developing States[10].

The purpose of this paper is to summarize the (I) current state of groundwater on SIDS, (II) potential impacts of climate change to groundwater on SIDS, and (III) importance of groundwater resources in climate change mitigation on SIDS. GRAPHIC's SIDS studies are highlighted, including several from the Pacific, Caribbean, and other regions of the globe. This paper is part of a series of GRAPHIC publications following the release of the GRAPHIC position paper[11] in 2015.

I. CURRENT STATE OF GROUNDWATER ON SIDS

Water resources on SIDS are limited and particularly vulnerable to human-induced and natural stressors. The reliability of a clean and available water supply is a critical problem on many SIDS at present and one whose urgency will increase in the future[12].

A recent (2014) assessment is available that documents aquifer conditions and groundwater resources on 43 SIDS[13]. The SIDS groundwater system assessment was conducted as part of the Global Environment Facility (GEF) Transboundary Waters Assessment Programme (TWAP), which is overseen by UNESCO-IHP and IGRAC.

Groundwater is an important source of freshwater on many SIDS (Fig. 1). Groundwater on SIDS is found in two main aquifer types: freshwater lens and perched. A freshwater lens float on top of denser salt water that often saturates the deeper parts of an island base (Fig. 2). The freshwater lens and deeper salt water are separated by a relatively thin transition zone of mixed fresh and salt water. The freshwater lens is often thickest beneath the center of the island, where the water table is mounded above sea level, and thinnest near the coast. The size and extent of freshwater lens represents an equilibrium between the amount of water recharging (precipitation, irrigation return flow, seepage beneath rivers and lakes) and discharging (to the ocean and extraction from wells) the lens. Perched aquifers occur on SIDS over horizontal confining (low permeable) layers or in compartments by a series of vertical volcanic dikes[14].

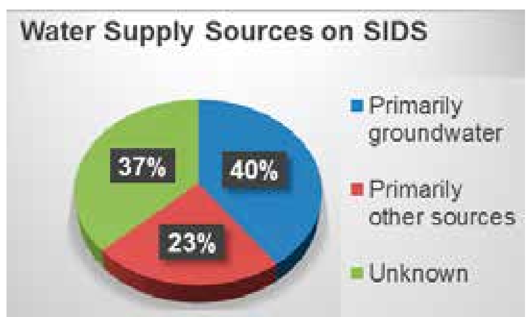


Fig. 1. Water supply sources on SIDS[13].

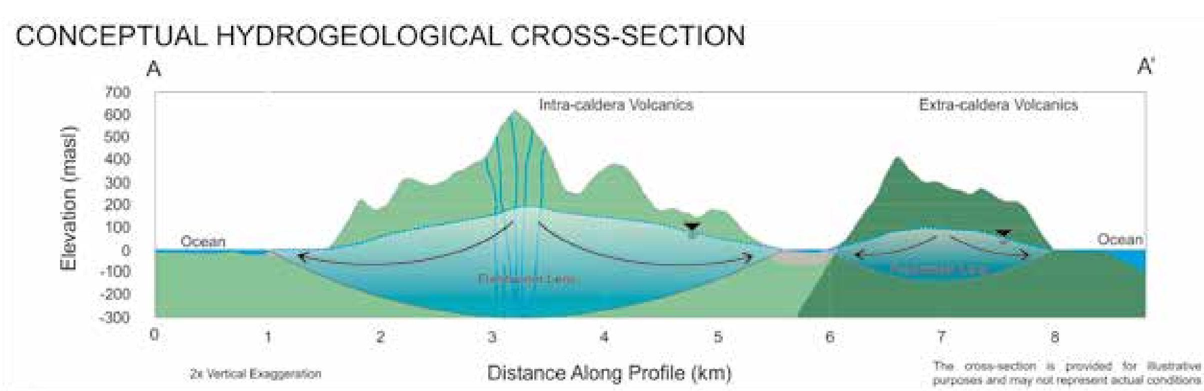


Fig. 2 Example of freshwater lens on American Samoa[13].

II. POTENTIAL IMPACTS OF CLIMATE CHANGE ON SIDS GROUNDWATER

SIDS are vulnerable to human-induced and natural stressors.

SIDS share many similarities that enhance their vulnerability and reduce their resilience to climate variability and change, including their physical size, remoteness, population growth, proneness to natural disasters and sensitivity to climate extremes, extreme openness of economies, and restricted capacity and resources[12]. Most SIDS have a limited freshwater supply, which is present as a freshwater lens surrounded by saline groundwater. Thus, water resources on SIDS are especially vulnerable to human-induced and natural stressors.

Groundwater availability on SIDS is threatened by overuse and contamination.

Groundwater availability on SIDS, as with many coastal regions worldwide, is threatened by withdrawal and depletion rates that have increased markedly in recent decades[15–17]. Groundwater overdraft to support irrigated agriculture, municipal use, and the economically important tourism industry is particularly problematic for SIDS. Seawater intrusion in coastal aquifers is caused by groundwater withdrawals and overdraft to help meet the freshwater demand for more than one billion people living in coastal zones[7,18]. Seawater intrusion on SIDS has generally increased between 2000 and 2010 (Fig. 3).[13] Exacerbating the problem is that coastal regions are generally water-scarce and undergoing rapid population growth[18,19].

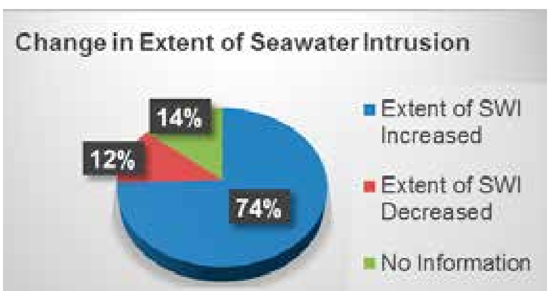


Fig. 3. Change in the extent of seawater intrusion on SIDS over 2000-2010[13].

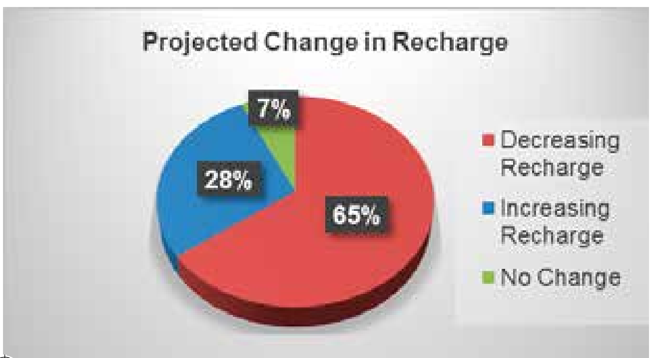


Fig. 4. Projected change in recharge on SIDS[13].

Reliability of freshwater on SIDS is a critical problem.

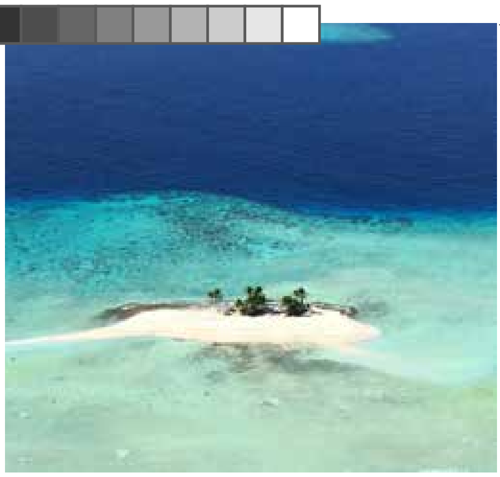
The reliability of a clean and available water supply is a critical problem on many SIDS at present and one whose urgency will increase in the future[12]. Under most future climate change scenarios, freshwater resources in SIDS are likely to be seriously compromised due to the projected changes in distribution of rainfall, which may decrease recharge (Fig. 4).

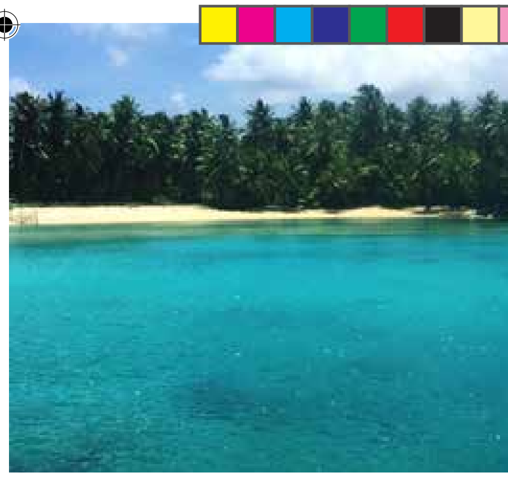
Climate induced sea-level rise will reduce groundwater supplies on SIDS.

Sea-level rise is projected to extend the areas of seawater intrusion and salinization of coastal groundwater, resulting in a decrease of freshwater availability for humans and ecosystems in SIDS and other coastal areas[12,20,21]. The rising sea levels may also affect groundwater quality because of the negative effects on urban stormwater drainage and sewage disposal caused by rising sea levels[12]. Of particular concern is the amplification effect between sea-level rise and the decrease in the thickness of freshwater lens on SIDS[22]. The effects of sea-level rise on coastal and island aquifers will be exacerbated by reduced recharge. Additionally, changes in freshwater runoff and submarine groundwater discharge (SGD)[23] can alter coastal water quality that affect the productivity of near-shore, marine ecosystems[12,24]. Water-related infrastructure in low-lying coastal areas is also vulnerable to damage from sea-level rise, flooding, hurricanes, and other storms.

Groundwater on SIDS is particularly vulnerable to extreme rainfall variations, storm surges, and other similar effects of climate change and variability.

Groundwater resources on many SIDS, especially low-lying, carbonate islands are inherently vulnerable because of limited land areas and quantities of groundwater safe for drinking, growing population and demand over supply, surface-water resources that are close to limits of sustainability, over-pumping of freshwater lens, saltwater intrusion, and pollution from human and animal waste[5,25,26]. Such vulnerabilities are exacerbated by tropical storms and climate change and variability, including projected precipitation decrease, evapotranspiration increase, and possible decreases in recharge rates.





For example, a storm surge from Hurricane Frances in 2004 contaminated the groundwater supply on North Andros Island, Bahamas[27,28]. After the storm surge, chloride concentrations in groundwater were nearly 30 times greater and orders of magnitude above than the World Health Organization drinking water guideline of 250 mg/L. Results indicate that the storm surge did not directly compromise the freshwater lens, but rather the trench and conduit system allowed direct infiltration and rapid intrusion of saltwater to the system after it became flooded with sea water. As a result, the trench and conduit systems on North Andros Island were pumped down to encourage recharge and dilution of the brackish groundwater[27,28].

El Niño/Southern Oscillation (ENSO)-induced drought can reduce recharge and the thickness of freshwater lenses on some SIDS.

Groundwater resources on low-lying SIDS in the Pacific Ocean, Indian Ocean, and South China Sea are especially sensitive to climate variability on interannual to multidecadal timescales. ENSO-related drought can reduce recharge rates and substantially reduce the thickness and extent of freshwater lenses[29]. Additionally, groundwater salinity on some Pacific SIDS is correlated with sea surface temperatures (SST) and the Southern Oscillation Index (SOI). Severe droughts have even forced the abandonment of several very small islands when fresh groundwater was exhausted[29]. During droughts it is critical to modify groundwater pumping on islands to sustain freshwater lenses. Additionally, a number of tree species on SIDS directly transpire from groundwater during dry periods and can substantially reduce the available groundwater and exacerbate the effects of drought on groundwater resources[29].

Trench system on North Andros Island[27].

III. IMPORTANCE OF GROUNDWATER IN CLIMATE CHANGE MITIGATION AND ADAPTATION STRATEGIES FOR SIDS

Groundwater has an important role in SIDS adaptation to climate change.

Groundwater on many SIDS provides a more secure, sufficient, and cost-effective water supply than surface-water resources. Use of groundwater will be important for many SIDS toward sustaining access to potable-water supplies. However, the sensitive nature of freshwater lens necessitates careful management of the groundwater resources.

POLICY AND GOVERNANCE

Improved governance is needed for sustainable groundwater resources on SIDS.

Groundwater resources on many SIDS are vulnerable to climate change and coupled human activities because of inadequate legislation and regulations, inappropriate national water policies that provide no clear priorities or directions to government agencies of responsibility, and very limited financial and human resources to manage groundwater resources and water supply systems[13,29] (Figs. 5. a,b).

Adaptive groundwater management must integrate regional water and agricultural policies.

SIDS can possibly achieve sustainable groundwater resources by effectively integrating regional water and agricultural policies that control illegal groundwater abstraction, create water banking infrastructure and policy (see Managed Aquifer Recharge below), and diversify crops and implement best available water-efficient irrigation[5]. Such a management approach must strike a balance between ecological protection, human development, economic growth, and acceptable socio-economic costs.

Community involvement on SIDS is necessary to establish groundwater sustainability goals.

Community involvement is critical in establishing sustainability goals for short- and long-term management strategies to succeed. This is especially true in many regions that lack participation of communities in water resource management and planning because of a disconnection between government ministries and communities[29].

Fig. 5. Policy and regulation for (a) controlling groundwater abstraction and (b) for groundwater protection on SIDS[13].

LAND USE

Land use on SIDS must optimize economic and adaptive benefits for the water sector.

Land-use policy and management practices that stabilize water availability is an adaptation strategy to increased precipitation variability and drought that may affect SIDS in the 21^{st} century[5]. For example, selective clearing of phreatophytes (water-loving vegetation), such as coconut trees, on some SIDS may increase recharge and the sustainable yield and decrease groundwater salinity[29]. However, the potential benefit for groundwater availability must be weighed against the subsistence communities and tourism that benefits from the trees.

Land ownership may hinder sustainable groundwater resource management.

On some SIDS in the Pacific region, land is often owned by traditional owners. This often leads to conflicts between governments and landowners when establishing water reserves on privately owned land. Because customary law in many SIDS in the Pacific region assigns ownership of groundwater to land owners, governments are often reluctant to enact water legislation specifying that water belongs to all people or the government or banning polluting land uses for fear of infringing on property rights[29]. As a consequence, some SIDS have no legal protection of groundwater from over pumping or from contamination.

ADVANCING SCIENCE AND ENGINEERING ON SIDS

Improve the linkage between groundwater monitoring and sustainable abstraction on SIDS.

A key adaptation strategy on SIDS is to improve sustainable groundwater abstraction based on better groundwater monitoring. The installation of observation boreholes and the regular monitoring of the transition zone are key steps for an improved understanding of the freshwater lens behaviour. Understanding the freshwater lens response to various conditions (e.g. extended dry periods, tidal influence, strong rainfall events) is a necessary first step before groundwater abstraction plans can be optimized to balance supply with demand. Groundwater abstraction using horizontal wells is an important management strategy to prevent early up-coning of saline water.

Managed aquifer recharge (MAR) is a promising adaptation approach for some SIDS.

Some SIDS will benefit from climate change adaptation strategies that incorporate suitability assessments of managed aquifer recharge (MAR) and artificial storage and recovery (ASR) projects. MAR offers the potential for a relatively low cost approach to capture and store excess stormwater in local aquifers during wet periods, which can be used to enhance the freshwater lens and off-set limited surface-water supplies during dry periods.

For example, MAR and ASR is used on the artificially conjoined island of Roi-Namur, which is part of Kwajalein Atoll in the Republic of the Marshall Islands[30]. Roi is the western lobe and Namur is the eastern lobe of the island (see Google Earth image below). Water supply on Roi-Namur Island is limited to surface catchment and storage during the rainy season, and pumping of the freshwater lens during the dry season and at times of drought.

On Roi, groundwater is pumped from a 1,000 m long horizontal lens well. The horizontal well has several pumps that skim water from the top of the water table to limit a cone of depression and upwelling of seawater into the freshwater lens.

Namur contains heavy vegetative cover and the groundwater is naturally recharged, without an MAR facility. A horizontal lens well exists on Namur, but it is not actively pumped for water supply. As a result, the freshwater lens on Namur is more indicative of natural atoll island settings and has an estimated 4.2 million gallons of freshwater[31]. In stark contrast, the freshwater lens on Roi is about 50 times greater (estimated 226 million gallons of freshwater) because of the use of MAR and relatively less vegetation and loss of groundwater to evapotranspiration on Roi[31].

The current ability to generate climate change scenarios for SIDS is limited using general circulation models (GCMs).

GCMs do not presently simulate sufficiently fine spatial resolution to generate scenarios for many SIDS without using statistical downscaling techniques[29]. Many GCMs also have considerable uncertainty for projected precipitation in the tropics because they do not simulate tropical convection well and do not presently reproduce some of the major modes of interannual to multidecadal climate variability, including ENSO[29]. Improved downscaling techniques, regional climate models, and finer resolution GCMs that are coupled with groundwater flow models will improve groundwater management and sustainability estimates on SIDS.

Vulnerabilities in engineered groundwater systems must be identified and mitigated.

For example, isolating and covering the trench and conduit system on North Andros Island will likely reduce the potential for inundation by future storm surges that are likely to affect The Bahamas[27]. The installation of rainwater harvesting cistern or large surface storage reservoirs might augment local-scale surface and groundwater supplies[29].

Improve human and institutional capacity and technical knowledge on SIDS.

Sustainable adaptive management of groundwater is critically important, especially on SIDS that are entirely dependent on groundwater as the only source of potable water. Yet, many SIDS lack the human and institutional capacity and technical knowledge base to identify the vulnerability of groundwater resources and implement adaptive water management strategies.

Two concrete-lined rainwater catchment basins on Roi (visible on image to left) are used to collect rainwater and artificially recharge groundwater when there is excess capacity
Sources : Google Earth

CONTRIBUTORS

Jason J. Gurdak
Coordinator of GRAPHIC
San Francisco State University
San Francisco, CA USA

Diana M. Allen
Dept. of Earth Sciences,
Simon Fraser University
Burnaby, Canada

Shannon Holding
Dept. of Earth Sciences,
Simon Fraser University
Burnaby, Canada

Tales Carvalho Resende
UNESCO International
Hydrological Programme (IHP),
Paris, France

Marc Leblanc
Coordinator of GRAPHIC
Universite d'Avignon et des Pays,
de Vaucluse, Avignon, France

Alice Aureli
UNESCO International
Hydrological Programme (IHP),
Paris, France

Mehrdad Hejazian
Dept. Earth & Climate Sciences
San Francisco State University
San Francisco, CA USA

Peter Swarzenski
U.S. Geological Survey
Santa Cruz, CA USA

Andreas Antoniou
UNESCO Centre IGRAC
Delft, The Netherlands

Aurélien Dumont
UNESCO International
Hydrological Programme (IHP),
Paris, France

REFERENCES

1. World Water Assessment Programme. *The United Nations World Water Development Report 3: Water in a Changing World*. 349 (UNESCO, 2009).

2. Siebert, S. *et al.* Groundwater use for irrigation – a global inventory. *Hydrol. Earth Syst. Sci.* **14,** 1863–1880 (2010).

3. Kløve, B. *et al.* Climate Change Impacts on Groundwater and Dependent Ecosystems. *J. Hydrol.* (2013). doi:10.1016/j.jhydrol.2013.06.037

4. Famiglietti, J. S. The global groundwater crisis. *Nat. Clim. Change* **4,** 945–948 (2014).

5. *Climate change effects on groundwater resources: A global synthesis of findings and recommendations*. (CRC Press, Taylor & Francis Group, 2012).

6. Green, T. R. *et al.* Beneath the surface of global change: Impacts of climate change on groundwater. *J. Hydrol.* **405,** 532–560 (2011).

7. Taylor, R. G. *et al.* Ground water and climate change. *Nat. Clim. Change* **3,** 322–329 (2012).

8. IGRAC. *Groundwater in the sustainable development goals: Position paper*. 8 (International Groundwater Resources Assessment Centre, 2014). at <http://www.youblisher.com/p/1042011-Groundwater-in-the-Sustainable-Development-Goals/>

9. UN-OHRLLS. *Small Island Developing States - Small Island Big(ger) Stakes*. 28 (United Nations - Office of the High Representative for the Least Developed Countries, Landlocked Developing Countries and Small Island Developing States, 2011). at <http://unohrlls.org/UserFiles/File/UN_SIDS_booklet_5x6-5_062811_web.pdf>

10. United Nations. *International year of small island developing states - 2014*. at <http://www.un.org/en/events/islands2014/index.shtml#&panel1-1>

11. Gurdak, J. J. *et al. GRAPHIC groundwater and climate change: Mitigating the global groundwater crisis and adapting to climate change*. 12 (UNESCO International Hydrological Programme (IHP), 2015).

12. *Climate change and water*. 210 (Intergovernmental Panel on Climate Change, 2008).

13. Allen, D. M. *et al. Assessment of SIDS groundwater systems - Transboundary Water Assessment Programme*. 43 (Simon Fraser University, 2014).

14. IGRAC. Small Island Developing States. at <http://www.un-igrac.org/areas-expertise/small-island-developing-states>

15. Konikow, L. F. *Groundwater depletion in the United States (1900–2008)*. 63 (U.S. Geological Survey, 2013). at <http://pubs.usgs.gov/sir/2013/5079>

16. Konikow, L. F. & Kendy, E. Groundwater depletion: A global problem. *Hydrogeol. J.* **13,** 317–320 (2005).

17. Wada, Y. *et al.* Global depletion of groundwater resources. *Geophys. Res. Lett.* **37,** (2010).

18. Small, C. & Nicholls, R. J. A global analysis of human settlement in coastal zones. *J. Coast. Res.* **19,** 584–599 (2003).

19. Millennium ecosystem Assessment. *Ecosystems and human well-being: Synthesis*. (Island Press, 2005).

20. Werner, A. D. *et al.* Seawater intrusion processes, investigation and management: Recent advances and future challenges. *Adv. Water Resour.* **51,** 3–26 (2013).

21. Uhlenbrock, K. The science and communication needed to help communities plan for sea level rise. *Eos Trans. Am. Geophys. Union* **94,** 238 (2013).

22. Bobba, A., Singh, V., Berndtsson, R. & Bengtsson, L. Numerical simulation of saltwater intrusion into Laccadive Island aquifers due to climate change. *J. Geol. Soc. India* **55,** 589–612 (2000).

23. Gonneea, M. E., Mulligan, A. E. & Charette, M. A. Climate-driven sea level anomalies modulates coastal groundwater dynamics and discharge. *Geophys. Res. Lett.* **40,** 2701–2706 (2013).

24. Michael, H. A., Russoniello, C. J. & Byron, L. A. Global assessment of vulnerability to sea-level rise in topography-limited and recharge-limited coastal groundwater systems. *Water Resour. Res.* n/a–n/a (2013). doi:10.1002/wrcr.20213

25. Holding, S. & Allen, D. M. Risk to water security for small islands: an assessment framework and application. *Reg. Environ. Change* (2015). doi:10.1007/s10113-015-0794-1

26. Holding, S. & Allen, D. M. Wave overwash impact on small islands: Generalised observations of freshwater lens response and recovery for multiple hydrogeological settings. *J. Hydrol.* **529,** 1324–1335 (2015).

27. Bowleg, J. & Allen, D. M. in *Climate change effects on groundwater resources: A global synthesis of findings and recommendations* 63–73 (CRC Press, Taylor & Francis Group).

28. Holding, S. & Allen, D. M. From days to decades: numerical modelling of freshwater lens response to climate change stressors on small low-lying islands. *Hydrol. Earth Syst. Sci.* **19,** 933–949 (2015).

29. White, I. & Falkland, T. in *Climate change effects on groundwater resources: A global synthesis of findings and recommendations* 75–105 (CRC Press, Taylor & Francis Group, 2012).

30. Hejazian, M., Swarzenski, P., Gurdak, J. J., Odigie, K. & Storlazzi, C. Effects of land-use change and managed aquifer recharge on geochemical reactions with implications for groundwater quantity and quality in atoll island aquifers, Roi-Namur, Republic of the Marshall Islands. in *Abstracts with Proceedings* (AGU, 2015).

31. Gingerich, S. B. Ground-water resources and contamination at Roi-Namur Island. *Kwajalein Atoll Repub. Marshall Isl. US Geol. Surv. Water-Resour. Investig. Rep.* 95–4275 (1996).

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CONTACT INFORMATION

INTERNATIONAL HYDROLOGICAL PROGRAMME (IHP)

UNESCO / DIVISION OF WATER SCIENCES (SC/HYD)
1 RUE MIOLLIS
75732 PARIS CEDEX 15 – FRANCE
TEL: (+33) 1 45 68 40 01 – FAX: (+33)1 45 68 58 11

ihp@unesco.org – www.unesco.org/water/ihp

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