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COMMUNITY ESSAY

Climate-change mitigation and adaptation in small island developing states: the case of rainwater harvesting in Jamaica

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Author's Personal Statement:

This essay seeks to further the dialogue concerning climate-change impacts for small island developing states (SIDS). Climate-change adaptation and mitigation strategies must be developed to cope with changes such as shifting precipitation patterns, increasing evapotranspiration, and expanding saline intrusion into coastal aquifers and wells. While it is necessary to study all climate-change mitigation measures, this essay uses Jamaica as a case study to examine the utility of rainwater harvesting (RWH) in SIDS. What role can RWH play in providing a sustainable supply of water in a changing climate? Through various water demand and deficit scenarios, questions are answered regarding (1) how much rainwater can be harvested on the island given present and future precipitation patterns and (2) how much can RWH realistically curb water-supply deficits now and in the future. Water resources are directly linked to many other considerations, including infrastructure, energy, agriculture, and the overall economy. Exploring the aforementioned questions can help to facilitate more effective policy decisions for water resources given predictions for rainfall. It is my hope that this analysis spurs a broader reflection on what concrete actions SIDS should take to prepare for the water-resource impacts of climate change.

Introduction

Climate change presents great challenges for small island developing states (SIDS).[1] SIDS are generally low-lying and coastal nations that range in size from Papua New Guinea (more than 450,000 square kilometers or km^2) to Tokelau (10 km^2) (Schmidt, 2005). These nations are found throughout the world, although most of them are located in the wider Caribbean and South Pacific regions. Ninety percent of SIDS are in the tropics and many are members of the Alliance of Small Island States.[2] The Intergovernmental Panel on Climate Change (IPCC) has labeled SIDS as the nations most vulnerable to climate change (see Payet & Agricole, 2006). The United Nations Framework Convention on Climate Change lists the following characteristics of SIDS that render them particularly at risk (UNFCCC, 2005):

- Limited natural resources, with many heavily stressed from human activities
- Coastal concentration of population, socioeconomic activities, and infrastructure
- High susceptibility to frequent and increasingly intense tropical cyclones and associated sand and storm surges, and to droughts, tsunamis, and volcanic eruptions
- Dependence on freshwater resources that are highly sensitive to sea-level changes
- Relative isolation and significant distance to major markets
- High sensitivity to external shocks
- High population densities (and in some cases high population growth rates)
- Inadequate infrastructure
- Limited physical size, which eliminates some adaptation options to climate change
- Insufficient financial, technical, and institutional capacities.

These factors challenge the developmental prospects of SIDS by serving as a barrier to accessing foreign markets and developing domestic products and services. The susceptibility to cyclones and droughts prevents some industries such as agriculture and water-dependent manufacturing from operating at optimum levels. Limited size creates intense competition for land use (residential, agricultural, industrial, institutional, and conservational uses), which

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[1] For a list of SIDS, see http://www.un.org/esa/sustdev/sids/sidslist.htm from the United Nations Department of Economic and Social Affairs.

[2] Established in 1990, AOSIS is a coalition of small island and low-lying coastal countries that share similar development challenges and concerns about the environment. Member states of AOSIS work together primarily through their diplomatic missions to the United Nations.

makes land-intensive adaptive measures to climate change difficult.

This essay focuses on Jamaica to highlight the problems encountered by SIDs and devotes particular attention to an analysis of climate change and water resources in this Caribbean nation. Included is an overview of climate and precipitation in Jamaica, threats to water resources due to climate change, and rainwater harvesting as a possible response. The objective is to answer key questions regarding the potential of rainwater harvesting as a strategy to mitigate water shortages due to climate change.

The Climate-Water Nexus in Small Island Developing States

The climate-change impacts on water resources are especially troublesome for SIDS. These consequences include decreases in already limited freshwater availability (due to changes in rainfall patterns, saline intrusion of freshwater aquifers from sea-level rise, changes in El Niño intensity and frequency), increased incidence and intensity of floods and changes in storm tracks, impeded drainage and elevated water tables, and heightened frequency and severity of droughts (UNFCCC, 2005).

Extreme weather events pose health risks as well as cause physical and infrastructure damage. In the Caribbean, risks include insect-borne, rodent-borne, water-borne, food-borne, and respiratory diseases, and heat-related illnesses (Ebi et al. 2006). In May and September, 2002, Jamaica experienced major flooding that resulted in four deaths, relocation of 725 people, and infrastructure damages worth US$1 million (WHO, 2003).

The tourism industry, water resources, and climate change in SIDS are highly interlinked. Tourism is a major economic contributor in many small island countries. However, the coastlines that attract visitors are also at risk of damage due to climate change. Thus, in addition to the environmental and social consequences of climate change, SIDS may face disproportionate harm to the economy due to loss of tourism. For instance, tourism has been the most important economic sector in Barbados for the last twenty years and provides critical foreign exchange earnings (Emmanuel & Spence, 2009). Tourism also requires a high quantity of water to service hotels and related facilities and the high season often coincides with the dry periods of the year in many SIDS. The average consumption for hotels in Barbados, for example, is 678 liters per guest per day; tourists consume roughly 3.6 times more water per capita per day than residents (Emmanuel & Spence, 2009). Finding strategies to cope with the impacts of climate change on water resources is therefore particularly important for the small island tourism sector.

There are many reasons for mitigation and adaptation planning for climate change. One reason is the irreversible nature of some changes in climate (which we are already undergoing). Another reason is the uncertainty of future actions to curb climate change due to conflicting national interests and to time needed to develop new technologies and deploy existing technologies and strategies that will reduce greenhouse gas (GHG) emissions. Existing strategies include behavioral changes, such as changing our means of transportation (e.g., to mass transit, electrical vehicles), using energy-efficient devices (such as light bulbs and appliances), and consuming products with less embodied energy. However, there are also various barriers to effective climate change adaptation planning. In SIDS, these obstacles consist of long time scales (climate-change effects are gradual and a discount rate may be needed to appreciate the net present benefits of action plans) (Tisdell, 2008), disagreement about climate-change priorities (e.g., water availability, coastal protection, energy sources), scientific uncertainty about the time-path of climate-change impacts, and financial constraints to many stagnant economies.

In addition, some adaptation strategies pose serious socioeconomic challenges, especially those in response to sea-level rise (such as coastal retreat). This article focuses on one mitigation and adaptation strategy for Jamaica: rainwater harvesting (RWH). RWH, though an ancient and proven technology, is underdeveloped in national policy. However, it is an intervention worth analyzing and deploying for various reasons: RWH is easily deployable given the fact that materials are found locally and there is a basic familiarity with the technology, empowers households and communities through decentralized implementation, can be encouraged through mandates and tax benefits, and brings people closer to the water source thereby limiting wastage and encouraging water savings.

Water-Resources Adaptation in Jamaica

Even Jamaica, an island with abundant rainfall, can experience water shortages in the dry season, which begins in December and ends in April. These dreaded droughts, exacerbated by climate change, can bring water restrictions and economic hardship upon various industries and communities (such as tourism and agriculture-based areas). Jamaica's poorest households (measured by household per capita income) spend on average over 10% of their income on water, while in the United Kingdom, for example, spending 3% of family income on water is considered

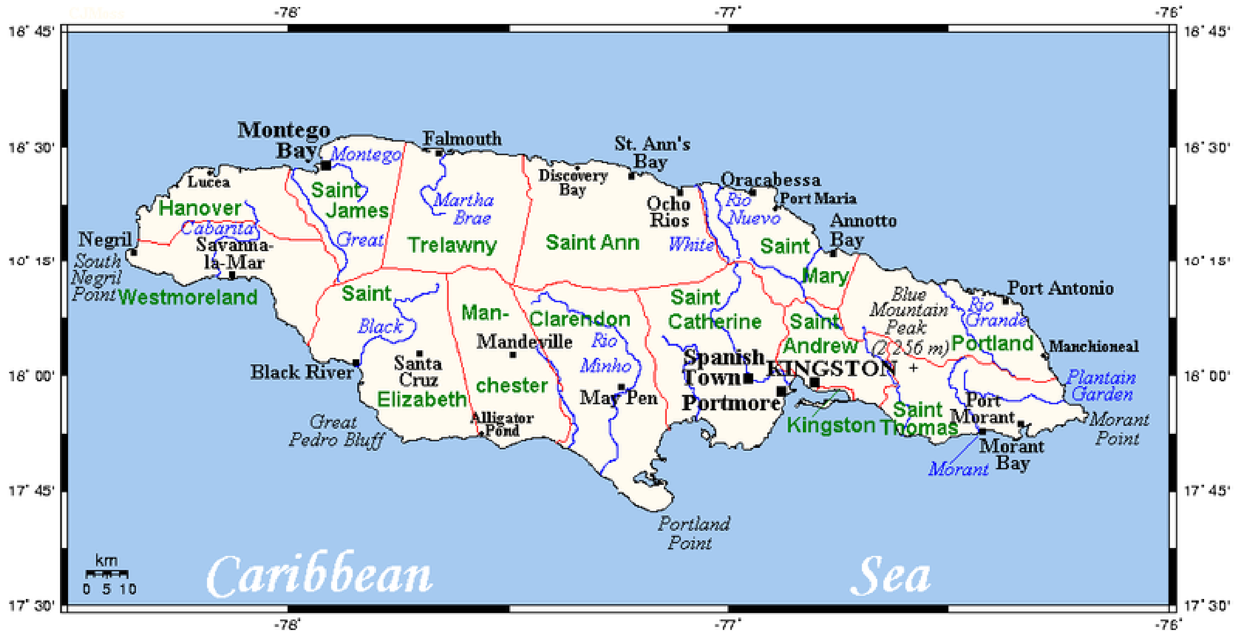

Figure 1 Map of Jamaica (adapted from Planiglobe).

the hardship threshold (UNDP, 2006). This statistic helps to demonstrate the important link between access to water and economic development. While Jamaica seeks to increase the proportion of its population with access to safe water, climate change challenges this goal. Implementing mitigation and adaptation solutions for water supply is thus imperative.

Climate and Precipitation in Jamaica

Jamaica has a tropical climate with average temperature ranges from 26°C in February to 30°C in August (WRA, 2011). The island experiences tropical storms and hurricanes frequently during the July to November season. Precipitation can vary both seasonally and spatially. The average annual precipitation from 1881 to 2007 was 1,871 millimeters (mm) (ESL Management Solutions Limited, 2009). The Blue Mountain area receives over 5,080 mm of annual rain, while the capital city of Kingston receives less than 762 mm (WRA, 2011). The dry season runs from December through April and coincides with the season of cold fronts (ESL Management Solutions Limited, 2009).

There are three rainfall-area characterizations in Jamaica: (1) heavy rainfall area (northeast section, Cockpit country (contiguous rainforest in Trelawny), parts of the parishes of Hanover and Westmoreland), (2) moderate rainfall area (north coast from Port Maria to Negril Point and the central regions of the island), and (3) low rainfall area (south coast between Bull Bay—on the southeast coast in St. Andrew—and Black River, as well as the north coast between Discovery Bay and Montego Bay) (Scientific Research Council of Jamaica, 1963). Figure 1 shows a map of Jamaica's parishes and rivers.

Climate Change and Jamaica's Water Resources

Climate change is expected to affect various aspects of the environment, especially water resources. Temperatures in Jamaica are expected to rise by about 1.5°C by the 2050s and by 2.8°C by the 2080s (ESL Management Solutions Limited, 2009). Some impacts of climate change on the water sector in Jamaica comprise shifts in precipitation patterns, a reduction in water availability in basins fed by shrinking glaciers (due to rising atmospheric temperature), an increase in algal blooms and reduction of self-purification capacity in water bodies (due to higher surface-water temperature), saline intrusion into coastal aquifers and wells (due to sea-level rise), and an increase in evapotranspiration (water availability reduction, lower groundwater levels) (Bates et al. 2008). Up to 80% of Jamaica's freshwater is supplied by groundwater, which can become salinated with sea-level rise (MACC, 2010). Changes in precipitation patterns will mean an extension in the length of the dry season (ESL Management Solutions Limited, 2009), an increase in frequency and intensity of floods and droughts (Bates et al. 2008), and a rise in stress during droughts for nonirrigated agriculture (irrigated agriculture accounts for only 9.3% of cultivated lands in Jamaica) (ESL Management Solutions Limited, 2009).

Table 1 Average Annual Rainfall for Jamaica.

	Average Rainfall (mm)*
Present*	1,861
2050	1,396
2080	1,117

*Using average of 1951–1980 30-Year Mean and 1971–2000 30-Year Mean

The National Water Commission provides most of the public water supply in Jamaica. In 2005, annual water production was nearly 300,000 megaliters (Ml) and annual water consumption was 94,415 Ml (ESL Management Solutions Limited, 2009). However, even without climate-change factors, there are three water-stressed catchments in Jamaica. The water stress is driven by a high demand from municipalities and industry for the Hope River (Kingston Basin), and irrigation needs in other locations (Rio Cobre and Rio Minho) (ESL Management Solutions Limited, 2009). The threshold for a water-stressed catchment is a demand-to-resource percentage of 40% (ESL Management Solutions Limited, 2009). The areas of the Hope River, Rio Cobre, and Rio Minho all fall into this category. The Hope River, which services the Kingston Basin, had a water *deficit* of 13 million cubic meters per year (m^3/yr) in 2005 (ESL Management Solutions Limited, 2009). This deficit is currently addressed through a water-supply transfer from the Rio Cobre and Yallahs basins. This strategy, however, may not be viable under changing conditions due to climate change. The Rio Cobre is expected to have a deficit of 40 million m^3/yr from 2050 and a deficit of 100 million m^3/yr from 2080 (ESL Management Solutions Limited, 2009).

A scarce water supply is one in which available water is less than or equal to 1,000 m^3/capita/year (Walling et al. 2005). Although Jamaica's internal renewable water resources provide 3,651 m^3/capita/year, increased drought due to climate change undermines Jamaica's water comfort. Of Jamaica's total water use, 49% is used by agriculture, 17% by industry, and 34% for domestic purposes. Total domestic water consumption was 293.6 million m^3 in 2007 (ESL Management Solutions Limited, 2009).

Overall, rainfall has decreased in the Caribbean in the last century (MACC, 2010). Climate-change scenarios using the PRECIS (Providing Regional Climates for Impact Studies) model show a decrease in precipitation in most regions of Jamaica by the 2050s (ESL Management Solutions Limited, 2009). PRECIS, an atmospheric and land-surface model that uses physical equations to simulate climate processes, can diagnose various meteorological variables. The model describes the following: dynamical flow, the atmospheric sulfur cycle, clouds and precipitation, radiative processes, and land surface and deep soil (Met Office, 2011). By the 2080s, significant precipitation decrease is projected to occur in the range from 25% to 40% (ESL Management Solutions Limited, 2009). Dry spells are also expected to increase. For the Montego Bay area, dry spells are expected to increase by 32% and 80% by the 2050s and 2080s respectively.

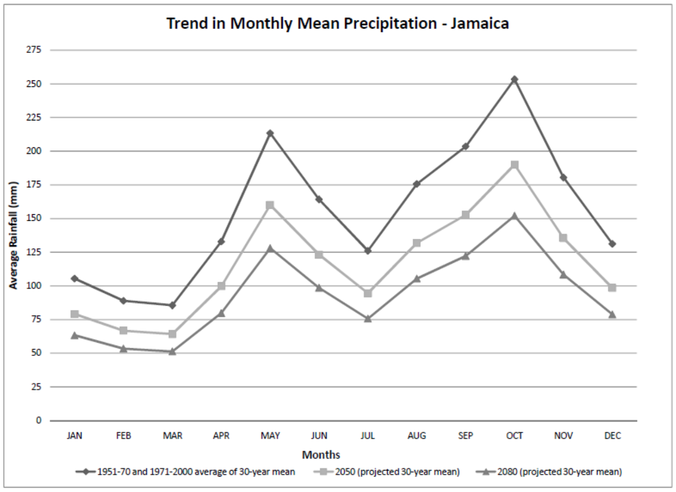

Figure 2 Mean 30-Year Monthly Rainfall for Jamaica.

Rainwater Harvesting in Jamaica

Although Jamaica's main climate-change concerns revolve around coastal inundation, sea-level rise, and damage by extreme weather events (MACC, 2010), mitigation and adaptation strategies are also needed to provide a sustainable supply of water. As Pandey et al. (2003) state, "Rainwater harvesting in response to climate extremes enhances the resilience of human society." There is global evidence showing the utility of constructing RWH systems to mitigate aridity and drought conditions. For example, in the Negev Desert, decentralized RWH in microcatchments yields 95,000 liters of water *per hectare* per year (Pandey et al. 2003).

Using an average of 30-year mean rainfall data for Jamaica (from 1951–1980 and from 1971–2000), Table 1 and Figure 2 illustrate the impact of climate change on precipitation using predictions from the PRECIS model. The year 2050 assumes a 25% reduction in average rainfall, while the year 2080 assumes a 40% reduction in average rainfall.

The following questions are answered given the aforementioned rainfall data, the total Jamaican land area of 10,990 km^2 (Aquastat, 1997), and assuming a stable Jamaican population (around 2.7 million island-wide and around 670,000 in Kingston), an average household size of five people, a roof-runoff

Table 2 Annual Domestic RWH Potential.

Target/Year	2000	2050	2080
RWH potential (m^3/yr)	72,500,000	54,400,000	43,500,000
% of domestic water consumption	24%	18%	15%

Table 3 Household-Catchment Area Needed to Meet Jamaica's Total Annual Water Demand.

Target/Year	2000	2050	2080
Catchment area needed (m^2)	104	138	173
% Increase from $80m^2$ baseline	30%	73%	116%

Table 4 Area of Runoff Needed for RWH to Meet Jamaica's Total Annual Water Demand.

Target/Year	2000	2050	2080
RWH runoff area (km^2)	56,100	74,800	93,500
% of Jamaican land area required	511%	681%	851%

Table 5 Percentage of Kingston Area Water Deficit Potentially Covered by Domestic RWH.

Target/Year	2000	2050	2080
River water deficit (m^3/yr)	-13,000,000	-40,000,000	-100,000,000
RWH potential(m^3/yr)	14,600,000	10,960,000	8,760,000
% of deficit covered by RWH	112%	27%	9%

coefficient of 0.9, an average roof size of 80 square meters (m^2) (CEHI, 2010), and using 2000 as a point of reference for the average of the 30-year mean rainfall data.

1. **Q:** Can domestic RWH meet the total domestic water consumption of roughly 300 million m^3/yr today and in future years?

   A: When it comes to household-water consumption, domestic RWH can provide nearly a quarter of water demand today and up to 15% of demand by 2080 (since, as the climate heats up, less recoverable water will fall). See Table 2.

2. The following two questions relate to catchment area and the ability to meet Jamaica's water consumption (e.g., demand). The findings indicate that space is a limiting factor for meeting water demand through rainwater catchment area methods, but improvements can be made to increase catchment sizes.

   a. **Q**: How much additional catchment area is needed at the household level to meet Jamaica's water demand of 94,000 Ml?

      A: Assuming an average household roof-runoff area of 80 m^3, a catchment-area increase of 30% per household is needed today, and more in the future given the projected reductions in rainfall due to climate change. See Table 3.

   b. **Q:** How much land area, in km^2, would be needed for Jamaica to meet its entire water demand by RWH (annual water consumption set to about 94,000 Ml)?

      A: There is technically not enough land area to harvest rainwater for *all* of Jamaica's water demand. See Table 4.

3. **Q:** For Kingston area residents, can domestic RWH meet the river-water deficits of today and the future given climate-change projections?

   A: Today, domestic RWH can meet the river-water deficit for the Kingston area (Hope River deficit). When climate-change predictions are taken into account, RWH can help alleviate the deficit (Rio Cobre water deficit) covering around 27% in 2050 and 9% in 2080. See Table 5.

Discussion and Limitations

The limitations of this study are linked to its scope: (1) an overview of the climate-change impacts on water resources in Jamaica and (2) answers to overarching questions regarding the annual RWH potential in Jamaica. This analysis was geared primarily towards RWH from household rooftops, but

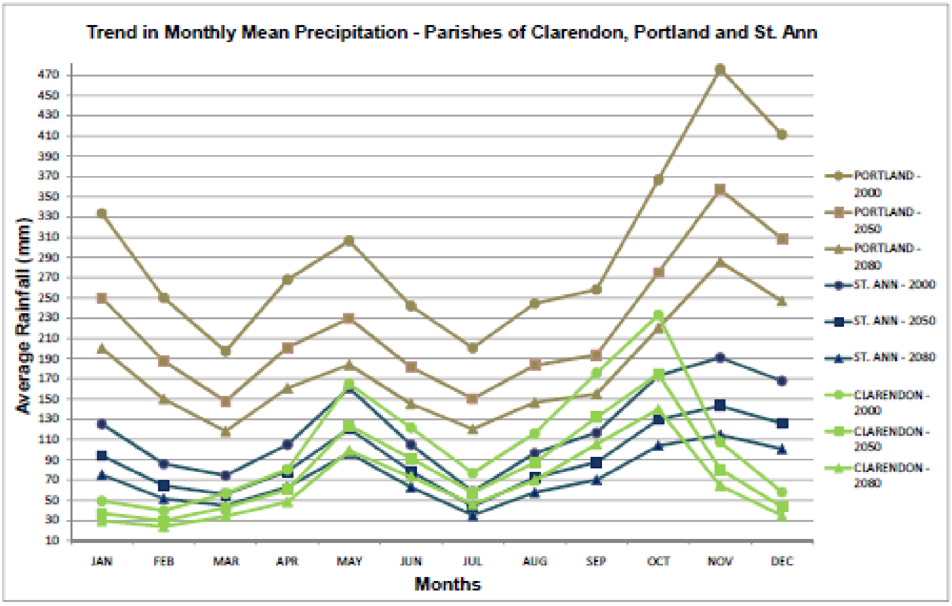

Figure 3 Mean 30-Year Rainfall for Clarendon, Portland, and St. Ann

many other buildings (e.g., educational, commercial, governmental) could be used. Different forms of catchments are also available, including land-surface catchments. In the parish of St. Ann, for example, there are community rainwater collection systems using slanted concrete areas on hillsides (Parchment, 2011). Many important elements of implementing a RWH system are beyond the scope of this work (such as purposes for which rainwater may be used, system design, and water-purification options). Yearly averages are used in the assessments, while monthly differences are useful for dry-spell management.

The results from this analysis are oriented around island-wide rainfall (with the exception of one example from the Kingston area), but a parish-by-parish vision is also helpful given the geographical differences in rainfall patterns. Figure 3 shows the differences between the high rainfall parish of Portland and two low rainfall parishes—Clarendon and St. Ann. Essentially, the figures presented in this study will be higher for rain-abundant areas and lower for drought-prone areas. This analysis thus serves as a policy guide for mitigating the risk of drought with climate change. Other parts of the solution will include increased water efficiency across all industries, reclaimed water use, sustainable management of surface and groundwater, and innovative technologies. Public policies can target the drought-prone areas of Jamaica since they are the most critical. For example, pilot projects and policies that require RWH for new buildings, tax incentives for installing RWH collection devices, and public building retrofits, can be targeted first to parishes with the largest water deficit. To optimize space use, technical innovations such as combining RWH with the implementation of solar panels can be put into practice.

Conclusion

As the Jamaican proverb states, “When water trowweh I’ cyaa pick up,” [When water is thrown away, it cannot be picked up]. This adage indicates the precious status of water as a necessity not to be wasted. Even more so with climate change, SIDS must find ways to cope with less water availability. This study shows quantitatively the benefits and limitations of RWH. The Jamaican government currently allocates 0.1% of its total budget to water resources (ESL Management Solutions Limited, 2009). Policy initiatives, such as RWH mandates for all new construction and tax incentives to incorporate RWH into existing structures, are necessary to mitigate and adapt to the impacts of climate change on water resources. Given the economic importance of the tourism industry and the large quantities of water associated with it, policies could target hotels and buildings in the tourism sector for rainwater collection (i.e., rainwater can be used for laundry, flushing toilets).

The lessons learned from analyzing the Jamaican case study may be relevant to other SIDS, especially those expected to experience similar decreases in precipitation due to anthropogenic climate change. For example, a recent study shows that the dry season will become drier and the wet season will become wetter in the Seychelles; the increase in dry spells that resulted in drought conditions in 1999 are likely to occur under future climate change (Payet & Agricole, 2006). This trend in the Seychelles may call for more RWH to store water for later use during the dry spells. In Barbados, the fifteenth most water-scarce nation in the world, water availability is directly influenced by rainfall (80% of which is lost via runoff and evapotranspiration); rainfall is also expected to decline due to climate change, and saline intrusion of wells is anticipated to increase due to sea-level rise and low rainfall (Emmanuel & Spence, 2009). Seawater desalination using renewable energy has been recommended for some SIDS and may be critical to survival when combined with other adaptation methods such as RWH.

While SIDS account for less than 1% of global greenhouse-gas emissions (MACC, 2010), they risk bearing the brunt of climate-change impacts. Low-lying island atolls, such as Tuvalu and Kiribati in the Pacific Ocean and the Maldives in the Indian Ocean, are particularly at risk; most or all of their habitable land may be lost due to sea-level rise and erosion (Tisdell, 2008). Tuvalu has announced that its 11,000 citizens will have to leave permanently because they will not win the battle with sea-level rise (MACC, 2010). Hopefully, many SIDS will be able to effectively mitigate, adapt, and survive. Solutions to climate-change impacts on water resources will be key in this survival.

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