Assessment of the Vulnerability to Climate Variability and Change of Grenada's Water Sector

Prepared by

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Abbreviations

AE	Accredited Entity
AR4	IPCC's fourth assessment report
AR5	IPCC's fifth assessment report
BAU	Business as usual
CA	Climate Analytics, a consultancy firm
CMIP	Coupled Model Inter-comparison Project
GCF	Green Climate Fund
GCM	Global Climate Models
GIZ	Germany's agency for international development (Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH)
GoG	Government of Grenada
INC	Grenada's Initial National Communication to the UNFCCC
IPCC	Intergovernmental Panel on Climate Change
NAWASA	Grenada's National Water and Sewerage Authority
NCCP	Grenada's National Climate Change Policy
OECD	Organization for Economic Co-operation and Development
RCM	Regional Climate Models
RCP	Representative Concentration Pathways
SIDS	Small Island Developing States
SNC	Grenada's Second National Communication to the UNFCCC
UNFCCC	United Nations Framework Convention on Climate Change
VA	Vulnerability Assessment

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1. Introduction

This report summarizes the findings of a climate change vulnerability assessment (VA) of the water sector in Grenada. GIZ conducted the VA to support the preparation of the project "Climate Resilient Water Sector in Grenada" (CREWS, working title). The project is intended for submission to the Green Climate Fund (GCF). GIZ conducted the assessment between May and July 2017 jointly with stakeholders and authorities in Grenada. It was informed by knowledge obtained from:

- Reviewing policies and strategies of the Government of Grenada (GoG)
- Reviewing scientific publications and studies of reputable origin
- Available data on Grenada's meteorology and climatology
- An ensemble of five Global Climate Models (GCM) from the Coupled Model Inter-comparison Project (CMIP5) used for IPCC's fifth assessment report (AR5), produced by the consultancy firm Climate Analytics
- Scientific backstopping through the consultancy firm Climate Analytics
- Evaluating and computing data related to water production, storage, distribution, and consumption, mainly provided by Grenada's National Water and Sewerage Authority (NAWASA)
- Stakeholder inputs in consultative interviews, group meetings and a validation workshop
- Site visits

The climate change impact potential of a project is an essential element of assessing the feasibility of a GCF proposal, because the Fund was created with a dedicated "adaptation" allocation target. It is linked to the Fund's core mandate as an operating entity of the Financial Mechanism under the United Nations Framework Convention on Climate Change (UNFCCC) and is reflected in its first investment criterion "impact potential" (GCF/B.09/23 Annex III: Initial investment framework: activity-specific sub-criteria and indicative assessment factors). For GIZ as an Accredited Entity (AE) of the GCF, it is a necessary step when preparing a funding proposal to validate all NDAs' requests, such as Grenada's request to increase the resilience of its water sector, regarding its compatibility with the GCF's investment framework.

Objective, Methodology and Scope of the Vulnerability Assessment:

The objective is to assess the vulnerability of Grenada's water sector in order to validate the climate change impact potential of the CREWS project against the GCF's respective investment criterion.

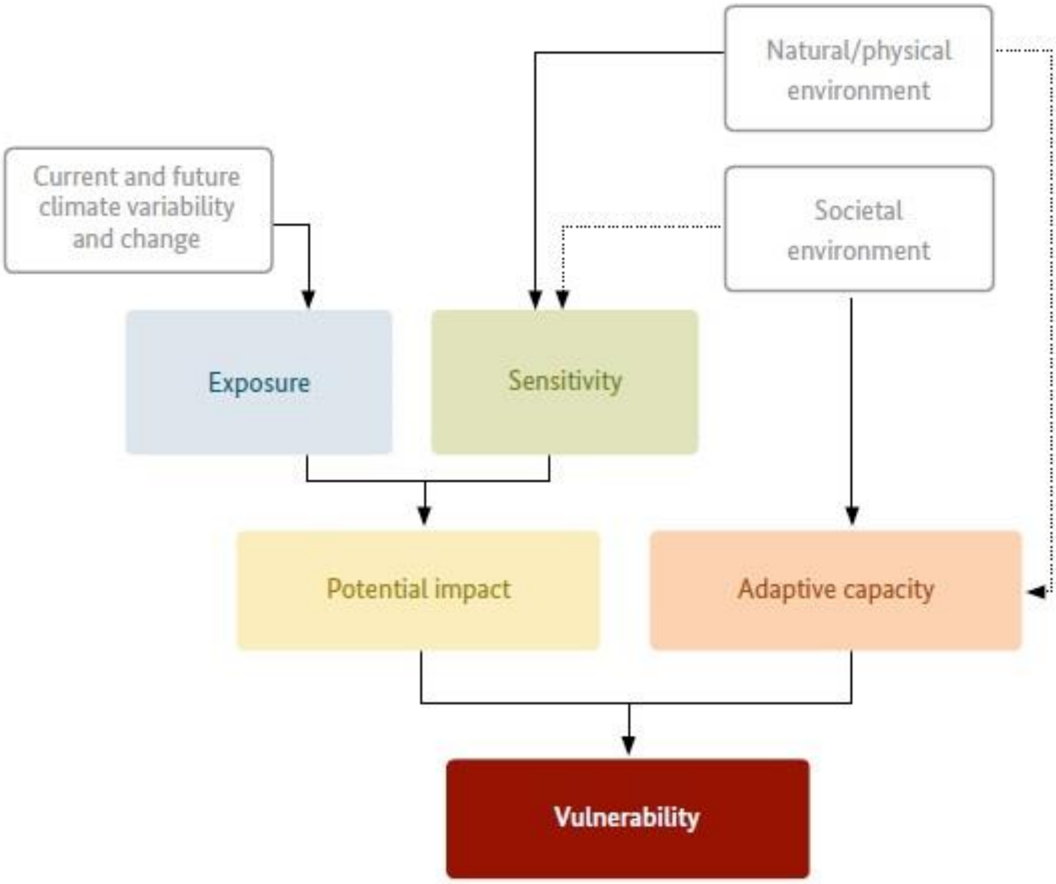
The concept of climate change vulnerability helps to better comprehend the cause/effect relationships linking climate change impacts with Grenada's water sector and, ultimately, its people and their livelihood in the tri-island state.

This assessment applied an interpretation of vulnerability based on the IPCC's Fourth Assessment Report:

"(...) the degree to which a system is susceptible to, and unable to cope with, adverse effects of *climate change*, including *climate variability* and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its *sensitivity*, and its adaptive capacity' (IPCC 2007 AR4 WG2, p. 883)."

In order to operationalize the function of vulnerability, this assessment applied methodological suggestions from the IPCC Assessment Reports 4 and 5, the GIZ Vulnerability Source Book (GIZ 2014), OECD Integrating Climate Change Adaptation into Development Co-operation (OECD 2012) and learning resources and examples at www.adaptationcommunity.net.

Figure 1:



Source: GIZ 2014 p. 20

The scope of the assessment is:

The geographical scope covers the entire territory of Grenada (348.5 km^2) taking the distribution of population (106,825 in 2015), economic activity and poverty vis-à-vis water availability into account and therefore focusing on Grenada mainland and Carriacou island.

The thematic focus of this VA is both on the presently experienced climate variability, projected climate variability and change, the impacts on water availability for Grenada's population, as well as the adaptive capacities of water users, public institutions, water governance and regulation, the GoG's public finances, and public and private water infrastructure.

The VA's focus is on the time period up to the year 2050. It is important to note that the IPCCs definition of vulnerability includes climate variability and extremes, which the IPCC defined as "…variations […] of the climate on all temporal and spatial scales beyond that of individual weather events (IPCC 2007 AR4 WG2, p. 872)".

The inclusion of climate variability is particularly important for most Small Island Developing States (SIDS) including Grenada for the following reasons:

Infrastructure lifecycles: Grenada maintains no complex and large permanent infrastructures on long-term cost-recovery strategies. The hardware and infrastructure input options, which are being considered for the CREWs project (see sections 5.2 below), are small and low-tech in comparison to non-SIDS. They will have exceeded or be approaching the end of their physical or economic lifecycle by mid-century. Long-term GCM projections for the end of the century are not applicable here. Present-day climate variability, however, is important.

Limitations of climate models: Climate change impacts for the next 30 years depend largely on historic emissions that are already locked into the global climatic system (IPCC AR5 Synthesis Report SPM). Impacts beyond 2050 have a higher dependency on greenhouse gas concentrations, which can be modeled in global and regional climate models based on different plausible development and greenhouse gas concentration pathways. Models integrate inherent residual uncertainties for example lack of climate data, population growth, economic growth, availability and distribution of technologies, social and political factors and so on. They are thus more suited to slow-onset long-term climate change trends such as mean annual near surface temperature or sea level rise. Extreme seasonal or weather events, which are sometimes of more immediate concerns to some SIDS including Grenada, are more difficult to project in frequency or intensity, and such modeling results are produced with lower confidence. Models therefore provide a limited basis for iterative decadal adaptation planning and are often perceived as less relevant by the general public, businesses and policy-makers with a need to prioritize for the next 5-10 years (GIZ 2014 p. 50).

The UNFCCC acknowledges this fact and advises parties in Article 3 Principle 3 to "…take precautionary measures to anticipate, prevent or minimize the causes of climate change and mitigate its adverse effects. Where there are threats of serious or irreversible damage, lack of full scientific certainty should not be used as a reason for postponing such measures..." (UNFCCC 1992).

With respect to adaptation planning for SIDS, the IPCC acknowledges a "lack of quantitative published assessments of climate risk for many small islands" and recommends "that future adaptation decisions have to rely on analogs of responses to past and present weather extremes and climate variability, or assumed/hypothesized impacts of climate change based on island type" (IPCC AR5 WG2, p. 1634). This VA has come to the same conclusion for Grenada and accordingly applied these recommendations by focusing on presently experienced variability and extremes as a departure point.

The assessment was structured as follows:

- Step 1: Grenada's climate change policy goals and strategies
- Step 2: Present climate variability and impacts
- Step 3: Projected climate variability, climate change and impacts
- Step 4: Vulnerability of Grenada's water sector
- Step 5: Theory of change and suggestions for logic framework

2. Grenada's Climate Change Policy Goals and Strategies

This section validates, (a) if the water sector is included in Grenada's policy priorities for integrating climate change into development planning, (b) what kind of vulnerability assumptions and assessments were used for deriving the adaptation policy priorities and if they are suitable for preparing the CREWS project, and (c) what kind of measures and activities were considered for increasing the resilience of Grenada's water sector.

Grenada contributed to the UNFCCC process right from the beginning. The Convention entered into force on the tri-island state on 09 November 1994. In the following years, the Government produced a series of studies and policies:

Figure 2:

2.1 Initial National Communication (INC 2000):

Grenada submitted its INC to the UNFCCC in the year 2000, which included a comprehensive VA on the basis of “what is currently known about Grenada’s vulnerability” (INC 2000, p. 20).

Summary of key assumptions:

Table 1:

Climate factor	Climate variability/change	Time scale
Annual mean near surface temperature	+1.0°C to 3.5°C	2100
Sea level rise	+15cm to 95cm	2100
Total annual precipitation	A positive or negative variation of 5% to 20%	2100
Wind speeds of tropical storms	+5 to 10 %	2100

Grenada’s most sensitive areas were identified as “(a) Water Resources, (b) Agriculture (c) Coastal Zones (d) Tourism and (e) Human Health (INC 2000, p. 20)”.

On the vulnerability of the water sector, the INC provides the following statements:

- “Grenada’s water resources are surface water based, with a groundwater potential to satisfy about 10% to 15% of the present potable requirement. On the smaller islands (Carriacou and Petite Martinique), domestic water is exclusively from rainwater catchments, while water for livestock is from groundwater. Little water is used in irrigation.” (p. 21)
- “Changes in weather patterns, particularly extreme events of rainstorms and droughts would impact negatively on the water supply.” (p. 22)
- “Sea level rise can lead to saltwater intrusion [which] would reduce the aquifer volume.” (p. 23).
- There is a risk of declining annual precipitation with wetter rainy seasons and severer and longer droughts, which could lead to domestic water shortages (p. 29).

Overall, the INC acknowledges high uncertainty and a lack of data and scientific studies to guide national planning and concluded that the combined impacts of climate change and variability on the water sector were “not clear” at the time of writing the INC in 2000 (p. 29).

Recommendations included more research and to strengthen water conservation techniques (p. 29).

Assessment: The INC clearly identified Grenada’s water sector as an adaptation priority based on a plausible vulnerability assessment taking a then limiting data situation and scientific uncertainty into account. The time scale is the year 2100 and therefore too far in the future. Due to these limitations, the INC had to remain at a rather general level and is suitable only for confirming the water sector as a policy priority, not for guiding detailed project preparation.

2.2 National Climate Change Policy and Action Plan 2007-2011 (NCCP-AP 2007):

Grenada produced the NCCP-AP in 2007. Concerning Grenada’s vulnerability, the NCCP-AP mostly referred to the INC’s assumptions and assessments including global climatic trends obtained from the then contemporary IPCC reports, very limited national data, stakeholder consultations and regional studies for the Caribbean. The assessment concluded: “…analyses and observations about [Grenada’s] climate sensitivity are consistent with the projections on the future impact of climate change in the Caribbean region (p. 3)”.

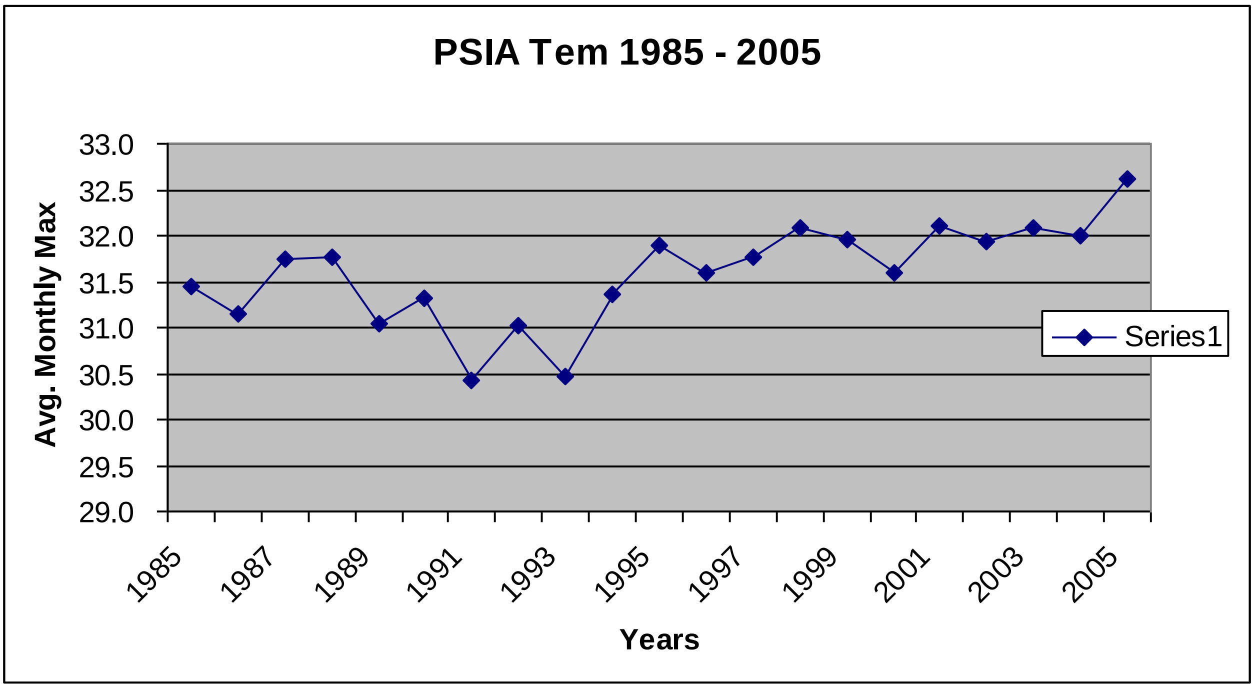
Summary of key assumptions:

Table 2:

Climate factor	Climate variability/change	Time scale
Annual mean near surface temperature	+1.8°C to 6.4°C	2100
Sea level rise	+0.18m to 0.59m	2100
Total annual precipitation	-25% in total rainfall, longer dry seasons, wetter rainy seasons, more intense rainfall when it occurs	n/a
Wind speeds of tropical storms	“more intense”	n/a

The NCCP-AP included domestic meteorological data on warming trends in Grenada with 2005 being the hottest year on record.

Figure 3: Historical average monthly max. temperatures



Assessment:

The NCCP-AP:

- Identified the water sector as one of Grenada’s most vulnerable sectors confirming the water sector as a policy priority
- Included an indication of warming as a factor of climate change that is already experienced on the tri-island state
- Had to remain at a rather general level due to a lack of data and scientific research
- Uses the year 2100 as time scale
- Is thus suitable only for confirming the water sector as a policy priority
- Is not suitable for guiding details of this GCF project preparation
- Didn’t recommend adaption activities for the water sector, but called for sector-specific vulnerability assessments and climate proofing exercises (p. 15)

2.3 (Intended) Nationally Determined Contribution (2015):

In 2015, Grenada submitted its Intended Nationally Determined Contribution (NDC 2015) to the UNFCCC Secretariat in the wake of negotiations for the Paris Agreement. An (I)NDC outlines a country's contribution to holding the increase in global average temperature to well below 2°C and in many cases its planned adaptation actions. When a country joins the Paris Agreement, INDCs become NDCs. Grenada signed and ratified the Paris Agreement on 22 Apr 2016. The NDC is an essential cornerstone of Grenada's climate change policy.

Grenada's NDC serves to communicate the climate action plan on mitigation and in addition includes some initial references to adaptation:

> "Grenada is particularly vulnerable to the impacts of climate change, as evidenced by the impacts of extreme events and the occurrences of increased forest fires, crop loss, water shortages and incidence of pests and diseases occurring in recent years. As such, Grenada recognizes the need to reduce its vulnerability and strengthen the resilience of its land and people to the projected impacts of climate change." (NDC 2015, p. 9)

Climate change is perceived as a serious burden and risk to the Grenadian economy "that is already in critical condition" (NDC, p. 1).

More specifically, Grenada's NDC identified water resource management as one of 4 priorities for adaptation action (NDC 2015, p. 9). The rationale is that a resilient water sector is "crucial to the long term development of Grenada as a nation" and that "improved capture, storage, distribution and conservation of water increases the adaptive capacity of individuals and communities" (p. 9).

The NDC referred to a recently developed "national adaptation plan and action plan for the water sector" (NASAP 2015 draft), which was reviewed in detail in this VA (see below). A number of activities suggested by the NASAP were recommended by this VA for the preparation of the CREWS project. The underlying vulnerability assessment, which was partially built on an earlier study (UN-ECLAC 2011), had some short-comings and was seen to be in need for some amendments and updates.

Assessment:

The NDC:

- Renewed Grenada's statement that the water sector is one of Grenada's most vulnerable sectors and re-confirmed the water sector as a policy priority
- Didn't include a vulnerability assessment or detailed recommendations for adaptation action
- Is thus suitable only for confirming the water sector as a policy priority
- Is not suitable for guiding a detailed GCF project preparation, but refers to partially suitable studies

2.4 National Adaptation Plan (NAP 2017 draft)

In May 2017, a final draft of Grenada's National Adaptation Plan (NAP 2017 draft) was readied to be forwarded to the Cabinet for approval.

> "The function of the National Adaptation Plan (NAP) is to provide a strategic, coordinating framework for building climate resilience in Grenada, recognising the need to develop the enabling environment for climate change adaptation as well as programmatic priorities (p. 10)".

It is a 5 year plan (2017-2021) with 12 multi-sectoral programmes of action (PoA) and 14 corresponding goals. The NAP dedicates the entire PoA 3 to "Water availability" including a detailed and budgeted list of recommended activities and estimated budget of approximately 50.2 USD Million (p. 86):

Update the National Water policy (2007) to include climate change considerations
Develop a watershed master plan for Grenada, Carriacou and PM • Complete detailed mapping of the different soil types of the watersheds, spatial variability and depth range of different soil types. • Analyze satellite data for change in soil pattern and ground truth with field data.

• Improve the land use classification system as per the standards used in the Caribbean, and update the land use map for each watershed. Note the change in the land use pattern for the last 10 years from satellite images as well as from aerial photographs. • Prepare draft Watershed Plan using the "Ridge to Reef" approach • Conduct consultations
Develop a Water Resource Master Plan • Integrate climate variability, land use change and the impact of increased urbanisation and population on available water resources in the new water resource report or master plan. • Conduct consultations • Implement the new water resource master plan.
Revise and expand GDS 79: 2006 "Specification for effluent from industrial processes discharged into the environment"
Promulgate regulations for monitoring of existing water quality
Promulgate regulations to establish and enforce standards and specifications for effluent discharges into receiving surface, underground or coastal waters
Revise fines for current legislation, specifically the Public Health Act and Regulations
Improve enforcement of existing legislation (public health, water legislation and other related legislation), through the provision of the necessary support from relevant government agencies
Provide incentives for the procurement of low-volume and low energy faucets
Make Rain Water Harvesting and Storage mandatory for all new building in Grenada, Carriacou and Petite Martinique (including industries, government) and develop incentives for engaging in this activity/ strengthen rain-water harvesting. Encourage rainwater harvesting for agriculture
Implement the National Drought management plan
Develop an improved methodology for acquiring meteorological and hydrological data: • Update data on all existing water resources (surface and ground) for Grenada, Carriacou and Petite Martinique, including the exact location of rain gauges in each watershed • Develop a policy for data collection and training for staff on the importance of data. • Audit equipment used for data collection for rainfall and water resources. Identify gaps and update them. • Install flood gauges to determine the level of flood waters after each event within the Chemin watershed. • Train community members and the staff of NAWASA and the Ministry of Health and Environment, to read flood gauge data to create spatial maps from successive flooding events.
Establish a framework and policy for water access: • Undertake an analysis of the amount of water needed for each housing area monthly, update the present data base and allocate allowance for increase in population for at least a 10 yr period. • Analyse the seasonal change in consumption with variation in rainfall pattern
Upgrade the National Water Information System online data access platform • Conduct an Information Technology Needs Assessment (infrastructure and institutional) for government departments that manage hydrological and meteorological data. • Upgrade the data management platform for each department. • Upgrade Information Technology equipment and develop skillsets
Create a central coordinating agency – a Water Resource Unit (as proposed in Water Policy) - which will be responsible for the management of water resources in a holistic manner
Assess the implementation of the National Water Sector Policy (2007) so far including Carriacou and Petite Martinique
Develop water balances for each major watershed:

• Calculate monthly water-budgets for each basin and then a final yearly water budget. • Conduct continuous analysis of the water budget using the rainfall, evaporation and storage data for effective management of water availability and projection into short, medium and long term time periods
Re-engineer the storm water drainage system in tri-island state • Assess the current drainage system and identify where new drains are needed and existing drains that need widening and re-grading etc. by prioritizing flood prone communities and followed by major townships • Undertake preliminary engineering design work • Select and clean silt from the mouth of rivers
Increase surface storage and improve the distribution system (including leaks): • Conduct a feasibility study to determine the best locations for additional surface storage and the type of storage. • Based on existing plan for improving the distribution system, mobilize additional investments • Quantify losses within the distribution network/ reservoirs • Develop a plan for how water losses are being reduced, including identification of leakage hot spots
Implement Water Resources Investment Programme • Develop alternative modalities for water resources (solar-powered desalination plant, community-based rainwater harvesting) • Develop and start the implementation of a reforestation programme to improve water catchment
Develop revised water tariff rates • Determine water pricing towards sustainable water services. Components will be 1) Water policy objectives and water pricing and 2) Water pricing mechanism's and instruments: levies, taxes and charges; • Analyze the revenue potential and administrative complexity of alternative pricing instruments
For Carriacou/PM: Rehabilitate/repair existing water catchment areas and improve watershed management including the Dumfries dump
For Carriacou/PM: Extend a reticulated water supply system to the main communities in the northern half of the island, from the Salt-Water Reverse Osmosis plant located at Beausejour
Develop public education and media campaign on the impacts climate change on the water resources
Promote water reclamation and re-use technologies, specifically in tourism and industry sector
Carriacou and PM: Provide community advisory bulletins on a continuous basis on water consumption patterns using data from the Salt-Water Reverse Osmosis plant

<u>Assessment:</u>

The NAP:

- Reiterated Grenada's statement of the water sector being one of Grenada's most vulnerable sectors and re-confirmed the water sector as a policy priority

  → The NAP is thus suitable for confirming the water sector as a policy priority for project preparation.
- Referred to the INC 2000 (see above) and forthcoming NCCP 2017-2021 (see below) for underlying vulnerability assessment, which had to remain at a rather general level

  → The NAP is not suitable for prioritizing activities based on a comprehensive vulnerability assessment.
- Included a detailed and budgeted list of recommended activities and estimated budget of approximately 50.2 USD Million

→ The listed activities are suitable for guiding a detailed GCF project preparation to a certain extent; many of the recommended activities were included in this VA for integration in the CREWS funding proposal (see below). However, the translation into a coherent and feasible project outline and the budgeting required further examination on the basis of a better understanding of the vulnerabilities of Grenada in general and its water sector in particular to enable infirmed prioritization.

2.5 National Climate Change Policy for Grenada, Carriacou and Petite Martinique 2017-2021 (NCCP 2017 draft)

At the time of writing this VA, the GoG was in the process of preparing an updated National Climate Change Policy for the period 2017 – 2021. One of the objectives of the NCCP will be to "build climate resilience in the following priority thematic areas: water supply and sewage management; agriculture, agri-business and food security; biodiversity and ecosystems; human health and coastal zone management (p. 14).

With the corresponding outcome to reduce "[…] water outage times during flooding and droughts, increased domestic and corporate usage of water conservation/efficiency measures, and reduced incidence of uncompliant surface, sub-surface and coastal water quality."

Assessment:

The draft is in early stages, so a detailed assessment would have been premature. However, the draft indicated a continued strong political commitment for adaptation in the water sector.

2.6 Second National Communication (SNC 2017 draft)

At the time of writing this VA, the GoG was in the process of preparing Grenada's Second National Communication and early drafts were circulated for comments.

Assessment:

The SNC has the potential to become an important resource document for this project, with comprehensive climate information and sector vulnerability assessments. But the draft was still in early preparation stages, so a detailed assessment or relying on the draft for preparing this project would have been premature.

2.7 Conclusion

This section aims to validate three guiding questions concerning the Government of Grenada's climate polices and strategies:

a) Is the water sector included in Grenada's policy priorities for integrating climate change into development planning?

b) What kind of vulnerability assumptions and assessments were used for deriving adaptation policy priorities and which of these assumptions and assessments can be utilized in preparing the CREWS project?

c) What kind of measures and activities were considered for increasing the resilience of Grenada's water sector?

Ad a):

The water sector is clearly a climate change policy priority for the Government of Grenada. It was marked out as a vulnerable sector and a priority area for adaptation action in all existing climate change policies. It was anticipated in Grenada's Initial National Communication in 2000 and, most recently, was included in the NDC in 2015, the draft NAP in 2017, and the draft update of Grenada's National Climate Change Policy 2017-2021. In addition, the Government commissioned two specific vulnerability assessments for the water sector (UN-ECLAC 2011 and NASAP 2015), which are reviewed in the following sections.

The policy-related leadership and ownership of the Government of Grenada was high and provides a strong justification for preparing the CREWS project.

Ad b):

Grenada's earlier policies had to remain at a rather general level of scientific analysis due to a lack of data and available research. The climatic changes expected by the Government are (a) increased annual mean near surface temperatures, sea level rise, less total annual precipitation (high uncertainty), and stronger tropical storms.

Identified vulnerabilities include Grenada's water resources, agriculture, coastal zones, tourism and human health.

The findings seem plausible, but would merit further examination of the underlying research. The VAs included in the policies alone are not suitable for prioritizing activities for the CREWS project. More recent research is currently integrated in upcoming policy updates, such as the NCCP 2017 draft and SCN 2017 draft, but these were not ready, yet. Existing policies are mainly informed by the IPCC and three key studies, UN-ECLAC 2011, Simpson et al. 2012 and NASAP 2015, which are reviewed section 3 below.

Ad c):

Grenada's policy documents provide little detailed guidance for project development. The exception is the draft NAP, which included a comprehensive and budgeted list of recommended activities at a total cost of approximately 50 million USD.

The activities suggested in the NAP are suitable to a certain extent for guiding a detailed GCF project preparation; many of the recommended activities were included in this VA and again recommended for integration in the CREWS funding proposal (see section 5.2 below).

The NDC referred to the NASAP study, which also included comprehensive recommendations for activities to increase the water sector resilience.

The translation of these recommendations into a coherent and feasible project outline and their budgeting requires further examination.

3. Impacts of Climate Variability and Climate Change

This section reviews the main climate impacts affecting the water sector in Grenada, namely temperature, precipitation, tropical storms, and sea level rise. First, this section takes stock of the available body of research about climate variability in recent years and future climate change impacts in Grenada. Secondly, it discusses recent results from a GCM ensemble employed by Climate Analytics on behalf of GIZ. The GCM ensemble comprised five GCMs of the Coupled Model Inter-comparison Project (CMIP5) used for the IPCC's fifth assessment report (AR5).

3.1 Review of Available Research

The body of research on climate change impacts in Grenada is small and sometimes the studies indicate limited confidence in the results. The research is generally informed by the IPCC Assessment Reports and four studies:

- UN-ECLAC 2011: An Assessment of the Economic Impact of Climate Change on the Water Sector in Grenada
- Simpson et al. 2012: CARIBSAVE Climate Change Risk Atlas (CCCRA) - Grenada
- NASAP 2015: Vulnerability and Capacity Assessment and a National Adaptation Strategy and Action Plan to Address Climate Change in the Water Sector for Grenada
- Climate Analytics (2017): Future Climate Projections over Grenada using CMIP5 Global Climate Models (commissioned by GIZ for preparing the CREWS project)

The first three studies produced climate modeling projections from a combination of multiple General Circulation Models (GCM) which are based on Coupled Model Inter-comparison Project (CMIP3) used for IPCC 4th Assessment Report (AR4), in some cases downscaled Regional Climate Models (RCM), and employed SRES scenarios (which were superseded by Representative Concentration Pathways since the latest fifth IPCC Assessment Report). The studies also reviewed available data on recent climate variability in Grenada and conducted stakeholder consultations.

In addition, In order to benefit from recent advances in climate science, CA 2017 analyzed more recent GCMs from CMIP5 used in AR5 based on Representative Concentration Pathways (RCP) scenarios. Utilizing projections of different model generations increases the robustness of the assessment. CA 2017 is based on RCP 4.5 and RCP 8.5 scenario resembling a scenario close to current policy projections (see Climate Action Tracker 2017[1]) and an extreme warming scenario without climate policy leading to more than 4°C global mean temperature increase by 2100. The impacts on Grenada could be greatly reduced, if the ambition is increased globally to achieve the 1.5°C temperature limit established in the Paris Agreement. However, to assess future vulnerabilities and required adaptation action, it is warranted to rather focus on scenarios closer to current policy projections or above. The above mentioned three reports, which are based on CMIP3 GCMs, have analyzed the scenarios which spans from less extreme (B1) to a more extreme (A2) scenario, with B2 being a middle scenario. Consequently, the ranges shown in the following sub-sections are higher for the studies based on CMIP3-SRES scenarios as compared to CA (2017).

In the following, this report presents and discusses the findings of the three studies and contextualizes the more recent findings of CA 2017. The actual CA 2017 assessment report is available in Annex I below.

3.2 Temperature

Characteristics

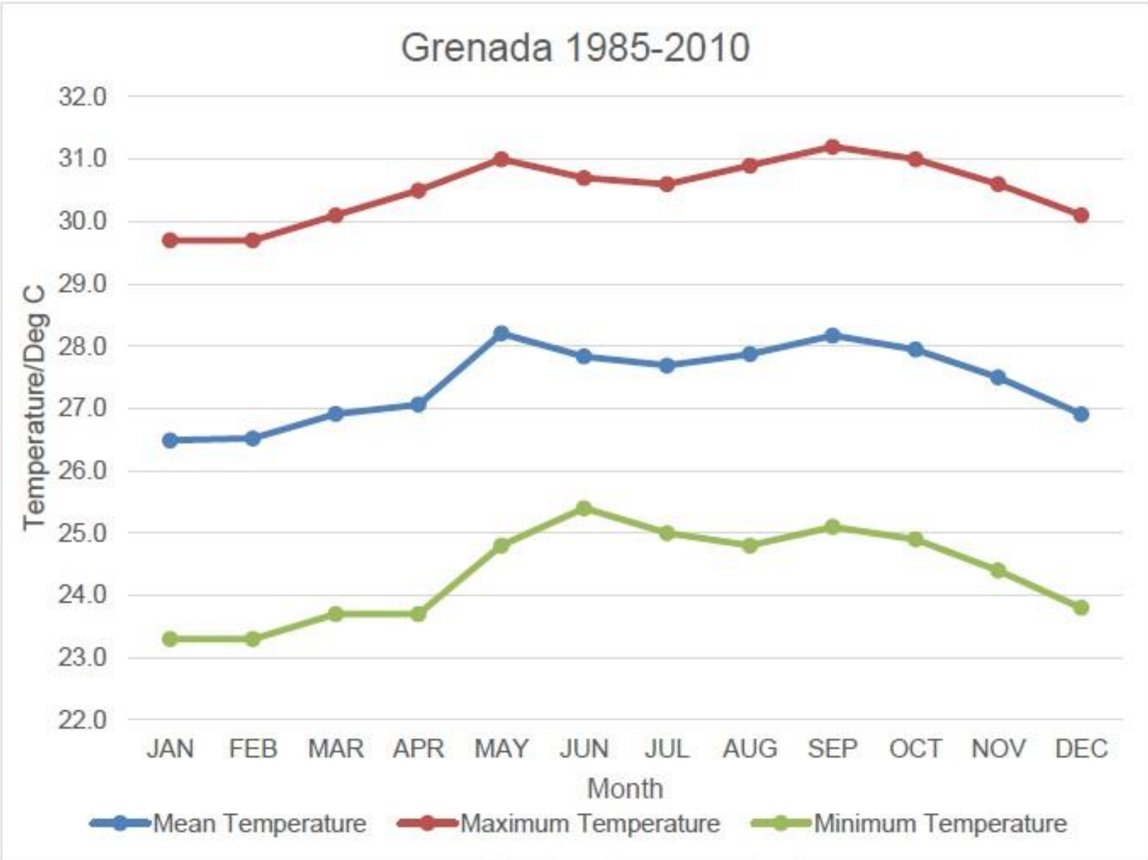
Grenada has a tropical climate. "Temperatures at sea level are generally high with little seasonal, diurnal or spatial variation due to the dampening or stabilizing effect of the adjacent ocean (UN-ECLAC 2011 p.21)". From NASAP 2015 p. 16: "The temperature climatology of Grenada is characterized by summer warming that begins to escalate in April and winter cooling beginning in December (Figure 2-3). The average diurnal

[1] http://climateactiontracker.org

temperature range is 6.2°C, with temperatures peaking during summer months. Maximum temperature values may exceed 31°C in these months, while minimum temperature values may fall below 20OC in January/February."

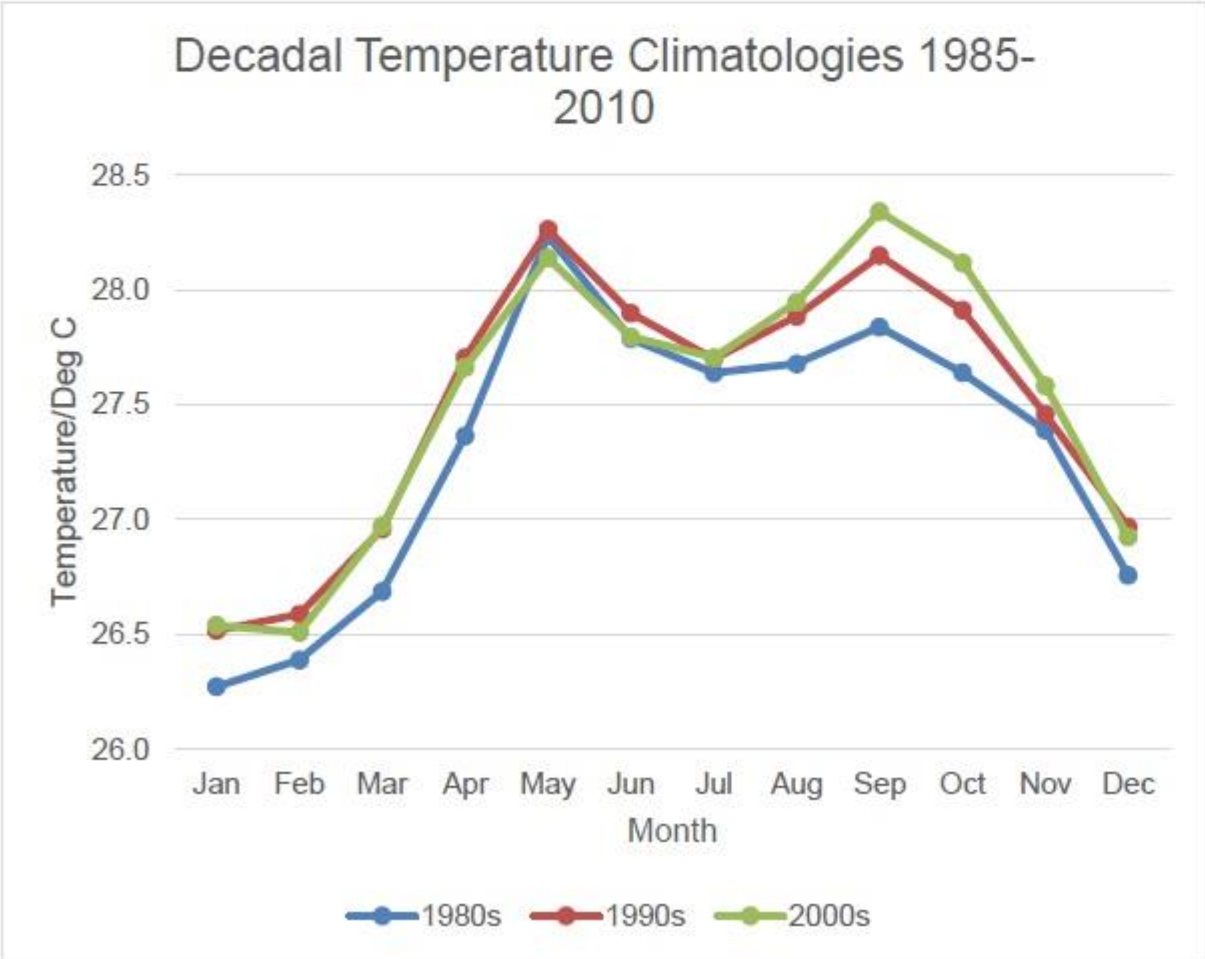
Past Trends

Figure 4:



"Observations from the gridded temperature datasets indicate that mean annual temperatures over Grenada have increased at an average rate of 0.14˚C per decade over the period 1960-2006. The observed increases have been more rapid in the seasons JJA and SON at rates of 0.16˚C and 0.15˚C per decade, respectively. Simpson et al. 2012 (p. 13): "The 2000s was the hottest decade on record (Figure 2-4) with the years 1998 and 2010 being the hottest year on record. NASAP 2015 reports with regard to temperature extremes: "There is insufficient daily observational data to identify trends in daily temperature extremes in Grenada. Simpson et al. 2012 (p. 22)"

Figure 5:



Future Climate Change

Future changes in mean and extreme annual temperatures are given in the table 3 and 4 below. As mentioned earlier, the three reports based on CMIP3 SRES scenarios used similar analysis approaches and their results are also very similar. For example, mean annual as well as extreme changes in surface temperature for 2060s from UN-ECLAC 2011 and NASAP 2050 show similar ranges.

Table 3:

Reference	**Change in Climate change (mean annual near surface temperature (ranges of the full ensemble))**	**Time scale**
UN-ECLAC 2011	+0.7°C to 2.60°C	2060s
	+1.1°C to 4.3°C	2090s
Simpson et al. 2012	+0.7°C to 2.2°C	2050s
	+2.4˚C to 3.2˚C	2080s
NASAP 2015	+0.3°C to 1.6˚C	2030s
	+0.7°C to 2.6˚C	2060s
CA 2017	+1.16°C to 2.17°C	2050

Table 4:

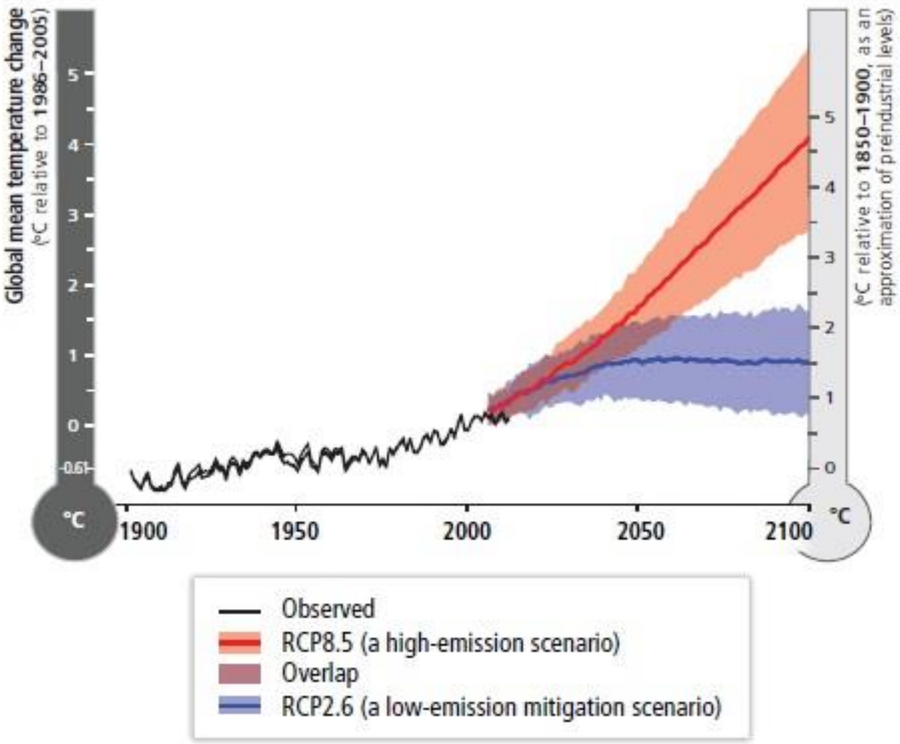
Reference	% change in annual frequency of hot days of full ensemble	% change in annual frequency of hot nights of full ensemble	Time scale
ECLAC 2011	+33 to 66	+33 to +83	2060s
	+41 to +89	+41 to +99	2090s
Simpson et al. 2012	+34 to +62	+34 to +82	2050s
	+38 to +90	+39 to +98	2080s
NASAP 2015	+33 to +66	+33 to +83	2060s
CA 2017	+56 to +86	+59 to +96	2050s

Results presented in the tables above clearly represent a warming in the future. Not only mean temperatures but also the extreme temperatures are projected to increase. The results are considered robust, because the increase is consistent in both CMIP3 and CMIP5 GCMs using the assumptions of SRES and RCP.

Summary

Past trends confirm increases in temperature in Grenada, which is consistent among different studies. The results further imply that Grenada is likely to experience a higher number of hot days as well as hot nights, which would increase overall exposure to heat. Confidence in the projections is high. This is in agreement with the recent IPCC AR5 WG2 SPM (p. 14):

Figure 6:



3.3 Precipitation

Characteristics

Most of the rainfall in Grenada occurs during the wet season from June-December ranging to as much as 65% of the annual rainfall (SNC 2017 draft p. 132). Carriacou and Petite Martinique experiences less rainfall than mainland Grenada and drought conditions occur on a regular basis (SNC 2017 draft p. 132).

SNC 2017 draft, p. 149: “During the Northern Hemisphere summer, the equatorial trough migrates northwards and Grenada is affected by the inter-tropical front (ITCZ). Intense rainfall during the wet season is caused by storms generated along this inter-tropical front, in addition to convectional thunderstorms usually occurring in the afternoons. The wet season usually spans the months of June to December, while the dry season usually falls in January to May. The main rainy season delivers approximately 75% of total annual rainfall, while approximately 16% of rainfall is received during the dry period at the start of the year. Rainfall observations at the Maurice Bishop International Airport indicate that the island receives a total of 116 cm of rainfall per year.”

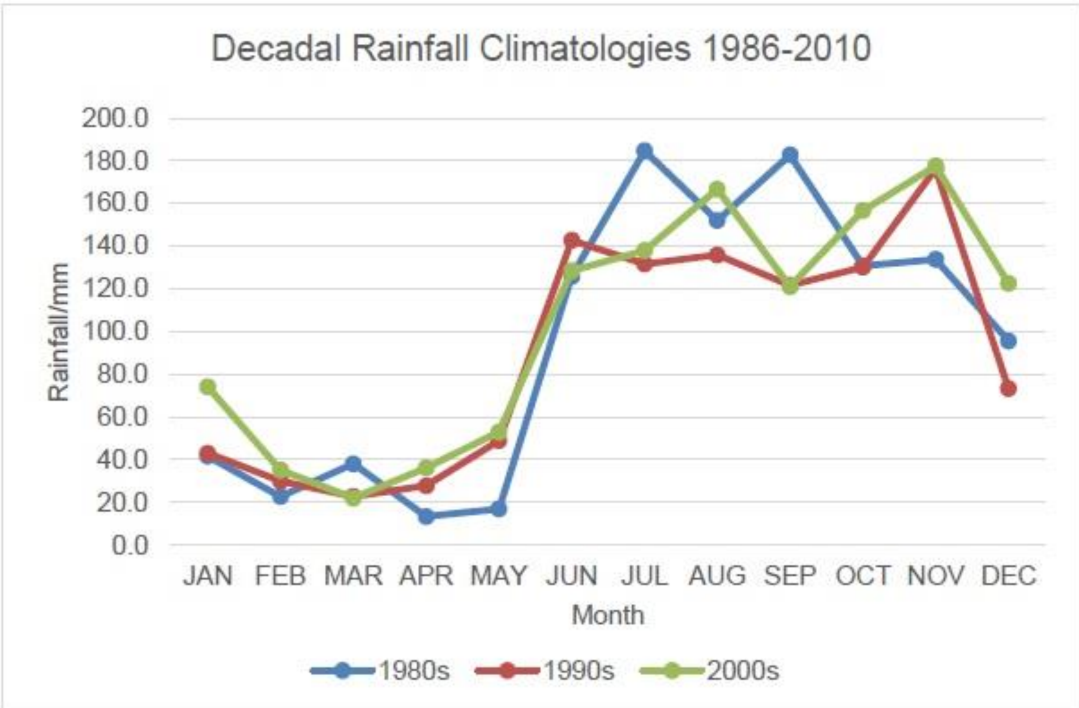
Past Trends

UN-ECLAC 2011 (p.20): “There is insufficient daily observational data to identify trends in daily rainfall extremes.”

Simpson et al. 2012 (p. 15): “Gridded observations of rainfall over Grenada do not indicate any significant of consistent trends over the period 1960-2006.”

NASAP 2015: “Grenada has experienced fluctuation in rainfall levels in past decades, along with a change in rainfall pattern through the year (p. 51). “Over the years, there has been a change in the amount of rainfall observed throughout the year, particularly during the wet season in the late part of the year (p. 14).” The study included no observation on changes in historical mean annual precipitation.

Figure 7:



Future Climate Change

Table 6 below shows future changes in mean annual rainfall from different studies at different time scales. Like temperature, the three reports based on CMIP3 SRES scenarios also show similar results for precipitation. It can be noticed from the results in table 6 that the full range of the models ensemble, which spans across different scenarios, are projecting a decrease as well as an increase in precipitation. However the signal is heavily tilted towards the decrease in precipitation. The signal in decrease in precipitation is further strengthened when looking at the results of the range of median of the full ensembles presented in

Table 6. Here, a relative decrease in all the time scales is observed for both RCP and SRES scenarios which may be considered as a robust signal.

Table 5:

Reference	Changes in mean annual precipitation (Range of Full ensemble)	Change in mean annual precipitation (Range of Median)	Time scale
Simpson et al. 2012 (p. 15)	-66% to +12% (GCMs)	-15% to -9%	2080s
	-36% to +10% (GCMs)	-16% to -8%	2050s
	-25% to +12% (GCMs)	-9% to -6%	2020s
NASAP 2015 (p. 35)	-25% to +12% (GCMs)	-11% to -4%	2030s
	-41% to +6% (GCMs)	-19% to -10%	2060s
CA 2017	-21.69% to 1.87%	-9.64% to -6.41%	2050

Extreme indicators for precipitation are given in table 5 and table 6 represented by changes in total precipitation falling in 1-day and 5-day periods respectively. A general trend across the world, as reported by IPCC AR5, is an increase in precipitation amount during such events in future. In addition, the IPCC projects an increase in extreme precipitation. However, for the case of Grenada, contrary to the global finding, we can see a mixed behavior with the results tilted towards decrease in precipitation especially in the Table 8. Similarly, the median values also remain close to zero in all the scenarios pointing towards no change in precipitation during the extreme precipitation events.

Table 6:

Reference	Changes in Max 1-day Rainfall (Range of Full ensemble)	Change in Max 1-day Rainfall (Range of Median)	Time scale
Simpson et al. 2012 (p. 25)	-7mm to +7mm (GCMs)	-1mm to 0mm	2080s
	-9mm to +6mm (GCMs)	0mm to 0mm	2050s
NASAP 2015 (p. 38)	-9mm to +5mm (GCMs)	0mm to 0mm	2060s
CA 2017	-15mm to +2mm	-11mm to -1mm	2050

Table 7:

Reference	Changes in Max 5-day Rainfall (Range of Full ensemble)	Change in Max 5-day Rainfall (Range of Median)	Time scale
Simpson et al. 2012 (p. 26)	-26mm to +9mm (GCMs)	-4mm to 0mm	2080s
	-17mm to +10mm (GCMs)	-5mm to 0mm	2050s
NASAP 2015 (p. 38)	-18mm to +7mm (GCMs)	0mm to 0mm	2060s
CA 2017	-25mm to +4mm	0mm to 0mm	2050

Summary

It may be concluded that Grenada has experienced fluctuation in rainfall levels in past decades, along with a change in rainfall pattern. However, the meteorological data in Grenada is not sufficient to derive any concrete historical trends. The island is represented by only one meteorological station at the international airport, which is not able to cover the diverse regions of the main island and the drier climates of Carriacou and Petite Martinique.

The uncertainty range of the full ensemble increases and decreases in total precipitation, but the results heavily tend towards a decrease. The range of median values points towards a relative decrease for all the time periods after taking all the scenarios into account. Therefore, it can be said with reasonable confidence that mean annual precipitation is likely to decrease over Grenada in the future. For the indicator examined for extreme precipitation, no significant trends could be found over Grenada, which is also in contrary to the IPCC finding, which points towards an increase in precipitation amount during the events of very heavy precipitation at global level.

3.4 Tropical Storms

Characteristics

NASAP 2015 (p22) "Grenada like most isles of the Caribbean is prone to experiencing Tropical Cyclones, Storms or Depressions between June 1 and November 30th each year. This is a phenomenon that is closely related to Grenada's rainfall pattern". Hurricanes have recently resulted in significant damage and losses throughout Grenada and its economy. Recent landfalling hurricanes were catastrophic extreme events for the island and its people, which are vividly remembered until today.

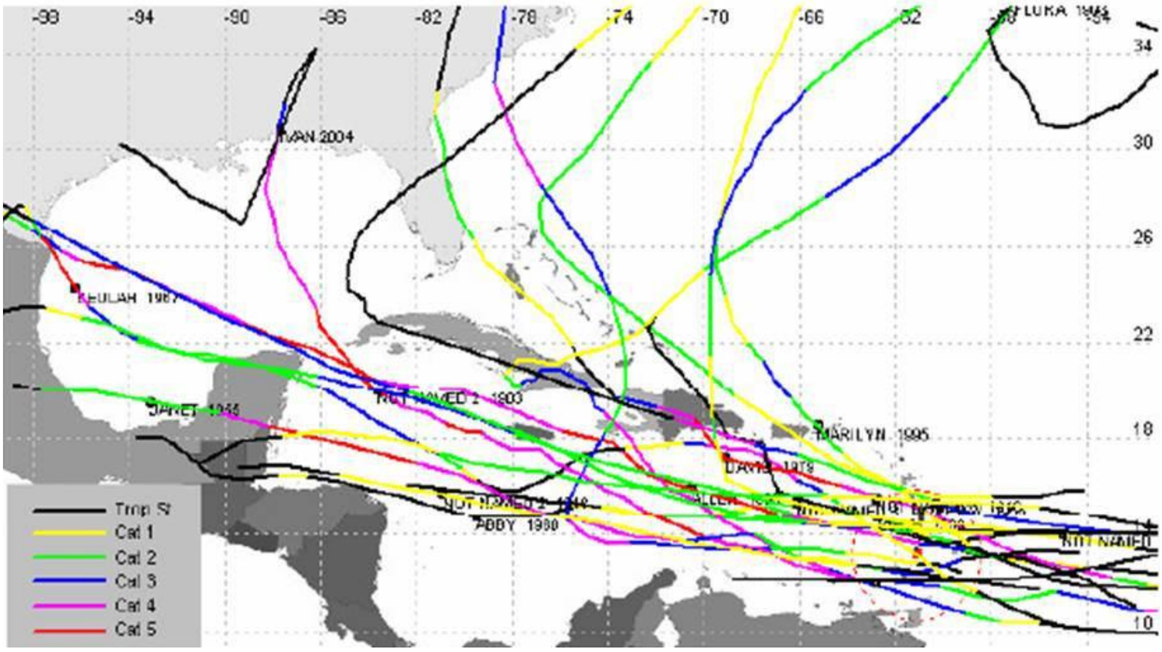
Past Trends

In 2004, Hurricane Ivan struck Grenada directly, and as a category 3 hurricane (later becoming category 5) with severe winds and rains that battered the island for over twelve hours. At their peak, wind speeds measured 193 km/h with gusts of over 233 km/h. It had particularly severe impacts for vulnerable groups, such as women, children, the poor, elderly and disabled. Grenada is still in the process of recovering from the impacts. Historic data and projections on tropical storms (cyclone activity in IPCC terminology) are therefore important to Grenada.

IPCC AR5 WGI TS (p. 17): "For the years since the 1970s, it is virtually certain that the frequency and intensity of storms in the North Atlantic have increased although the reasons for this increase are debated."

UN-ECLAC 2011 (p. 23): "Grenada lies on what used to be regarded as the southern edge of the Atlantic hurricane belt, so the islands were not affected as frequently as other territories further north. However, recent experience has seen hurricanes tending to move from across the Caribbean from farther south. In the last decade Grenada had hurricane strikes in two consecutive years – 2004 and 2005."

Figure 8: Caribbean Basin Storm Tracks (from UN-ECLAC 2011):

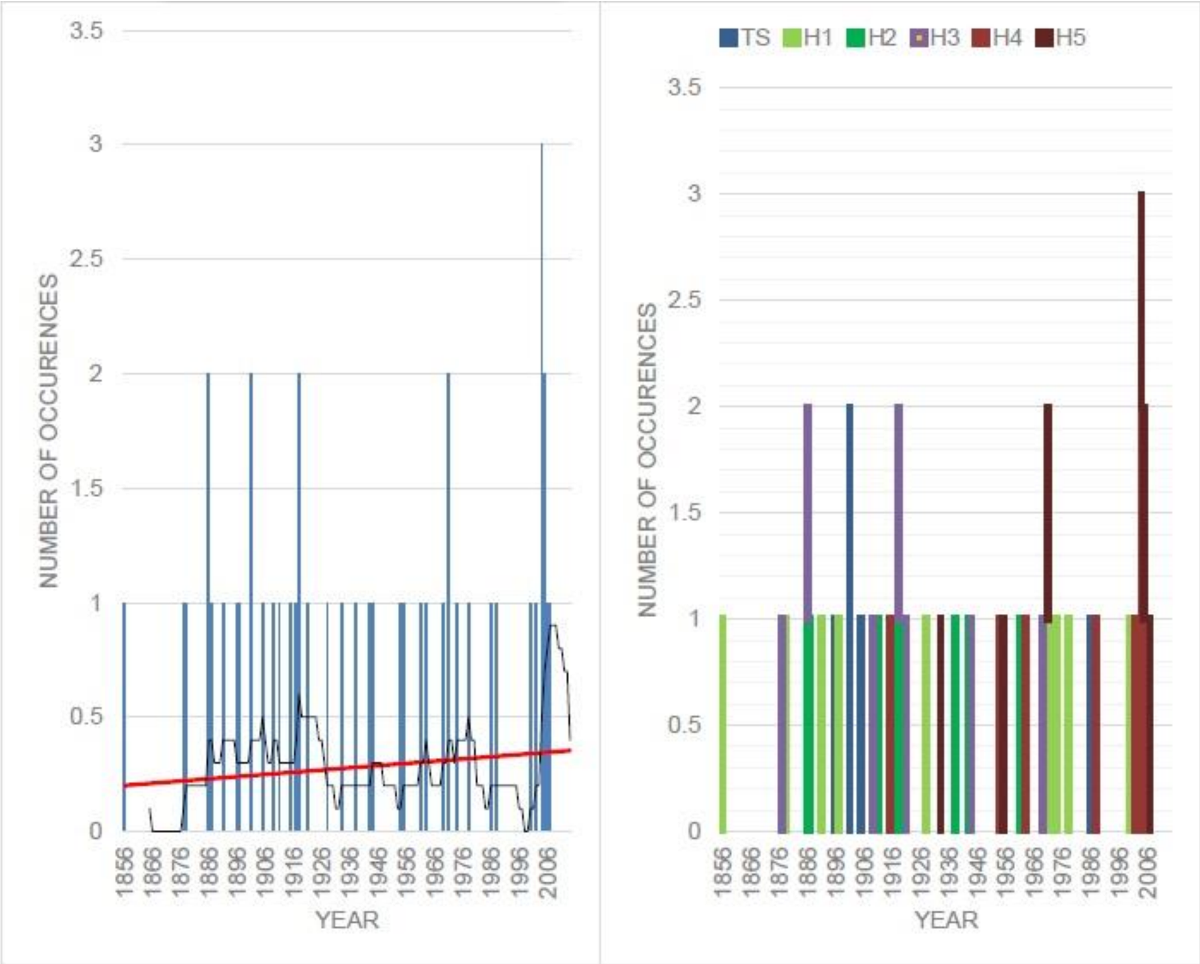


Simpson et al. 2012 (p. 17): "…increasing trends around Grenada during JJA and SON seasons over the period 1960-2006. The increasing trend in mean wind speed is 0.23 ms^{-1} per decade in JJA and 0.26 ms^{-1} per decade in SON."

NASAP 2015 (p. 17): "The historical trend suggests an increase in the number of hurricanes making landfall in Grenada."

NASAP 2015 (p. 41): "Landfalling hurricanes are taken to be hurricanes passing within a 100-km radius of Grenada. The historical trend suggest an increase in the number of hurricanes making landfall in Grenada. The 10-year running mean indicates a period of increased hurricane activity beginning in the year 2000 (Figure 2-14). However, at this scale, there are no discernible patterns in TC activity can be concluded. A closer look at the index reveals that recent peaks in TC activity are on account of increases in major hurricanes (Figure 1.2). There is a sharp increase in the number of Category 4 and 5 hurricanes starting in 2002, signifying an increase in the more intense storms. The records indicate a small increase in Category 1 storms, but a decline in Category 2 and Category 3 hurricanes."

Figure 9: Trends in occurances and intensity of tropical storms



Future Climate Change

Table 8:

Reference	Climate change (wind speeds)	Time scale
UN-ECLAC 2011, p.22	n/a	n/a
Simpson et al. 2012, p.15	JJA: -0.2 to +0.8 ms^{-1} and SON: -0.2 to +0.9 ms^{-1} (GCMs)	2080s
	JJA: +0.5 ms^{-1} and SON: +0.5 ms^{-1} (RCM ECHAM4 A2)	2080s
	JJA: +1.2 ms^{-1} and SON: +1. ms^{-1} (RCM HadCM3 A2)	2080s
NASAP 2015	n/a (refers to IPCC and others)	n/a

There are few robust results from GCMs, RCMs and downscaled projections that can add value to observed climate variability for development planning. The confidence in projected long term (centennial) changes in tropical cyclone activity and confidence is lower in region-specific projections of frequency and intensity is low (IPCC AR5 TS, p. 113). However, the body of available literature points towards a decrease in total number but increase in the occurrence of more intense cyclones in the future. IPCC AR5 TS (p. 107): "The influence of future climate change on tropical cyclones is likely to vary by region, but there is *low confidence* in region-specific projections. The frequency of the most intense storms will *more likely than not* increase in some basins." Simpson at al. (p. 17) sees signals towards increasing peak wind intensity. Acevedo 2016 suggested increasing wind speeds and stronger storms for Grenada in a recent Working Paper for the International Monetary Fund.

Summary

The available research provides lacks robust findings on the future of tropical storms in Grenada.

Historic data shows that Grenada already experiences an increase in wind speeds and hurricane landfalls including due to hurricanes of the Atlantic hurricane belt tending to move further south. Since Grenada comes under the influence of tropical storms originating from North Atlantic, the IPCC (IPCC AR5 WG1) found strong evidence for an increase in the frequency and intensity of hurricanes since 1970s in the North Atlantic.

Regarding the future projections, the IPCC further says: "while projections indicate that it is likely that the global frequency of tropical cyclones will either decrease or remain essentially unchanged, concurrent with a likely increase in both global mean tropical cyclone maximum wind speed and rainfall rates, there is lower confidence in region-specific projections of frequency and intensity".

Based on the historical trends as well as IPCC's statement on the future projections, it can be inferred that Grenada is more likely than not to see more intense hurricanes in future accompanied by very heavy rainfall events. [CA 2017, p. 6]"

3.5 Sea Level Rise

Past Trends

NASAP 2015 (p. 12): "Estimates of observed sea level rise from 1950 to 2000 suggest that sea level rise within the Caribbean appears to be near the global mean (2.0 ± 0.2 mm/year for 1971-2010)." "Grenada shows a mean sea level rise of 2.9mm/yr from 1950-2000." Simpson et al. 2012 applied the same approach as NASAP 2015.

Stephenson and Jones (2017) (p.12): "It is estimated that between 1901 and 2010, global mean sea level increased by 0.19 ± 0.02 metres (IPCC, 2013), although rates of sea level rise are not uniform across the globe and large regional differences exist. From estimates of observed sea level rise from 1950 to 2000, it is anticipated that Caribbean sea levels have risen at a rate similar to the global rate (Church et al., 2004). Table 9 below shows the trend of sea level rise across the Caribbean region."[2]

Table 9:

Table 3. Mean rate of sea level rise averaged over the Caribbean basin.

Period	Rate (mm/year)	Information source
1950 and 2009	1.8 ± 0.1	Palanisamy et al. (2012)
1993 and 2010	1.7 ± 1.3	Torres & Tsimplis (2013)
1993 and 2010	2.5± 1.3	Torres & Tsimplis (2013), after correction for Global Isostatic Adjustment (GIA)*

Future Climate Change

Table 10:

Reference	Climate change (sea level rise)	Time scale
UN-ECLAC 2011 (p.23)	+0.17m to 0.24m	2050s
	+1 to 2m	2100s
Simpson et al. 2012 (p. 29)	+0.13m to 1.45m	2100
NASAP 2015	+0.60m [0.41m-0.79m] relative to 1986-2005	2100
	+0.57m [0.40m-0.75m] relative to 1990	2090s

Stephenson and Jones (2017) (p.14): "It has been suggested that gravitational and geophysical factors will lead to the region experiencing a greater rise in sea levels than most global areas. In fact, sea level rise over the Northern Caribbean may exceed the global average by 25% (IPCC 2013). The table to the right indicates that Caribbean countries are projected to exceed the global average under all RCP scenarios. Under the worst-case scenario (RCP8.5), it is suggested that most Caribbean SIDS may reach 0.5-m SLR by the mid-century (2046-2065) and 1-m sea level rise by the end-of-century (2081-2100). Countries located in the southernmost Caribbean show marginally higher rates of increase, as in the case of Trinidad."

[2] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/605069/2._Extremes.pdf

Table 11:

Table 6. Projected increases in global mean sea level (in metres) and select Caribbean Small Island States Projections are taken using the CMIP5 suite of global climate models and are relative to 1986-2005.

		2046 – 2065		2081– 2100	
Variable	**Scenario**	**Mean**	**Likely range**	**Mean**	**Likely range**
Global Mean Sea Level Rise (m)	RCP2.6	0.24	0.17 – 0.32	0.40	0.26 – 0.55
	RCP4.5	0.26	0.19 – 0.33	0.47	0.32 – 0.63
	RCP6.0	0.25	0.18 – 0.32	0.48	0.33 – 0.63
	RCP8.5	0.30	0.22 – 0.38	0.63	0.45 – 0.82
Bahamas	RCP2.6	0.33	0.27 – 0.40	0.57	0.51 – 0.64
	RCP4.5	0.35	0.28 – 0.42	0.65	0.56 – 0.74
	RCP6.0	0.33	0.25 – 0.41	0.66	0.56 – 0.76
	RCP8.5	0.40	0.30 – 0.50	0.86	0.71 – 1.02
Belize	RCP2.6	0.37	0.29 – 0.45	0.64	0.58 – 0.72
	RCP4.5	0.39	0.31 – 0.47	0.74	0.63 – 0.83
	RCP6.0	0.38	0.29 – 0.46	0.74	0.63 – 0.86
	RCP8.5	0.44	0.34 – 0.56	0.97	0.80 – 1.15
Guadeloupe	RCP2.6	0.35	0.27 – 0.41	0.60	0.53 – 0.66
	RCP4.5	0.36	0.28 – 0.44	0.68	0.59 – 0.77
	RCP6.0	0.35	0.27 – 0.43	0.69	0.59 – 0.80
	RCP8.5	0.41	0.32 – 0.52	0.90	0.74 – 1.07
Jamaica	RCP2.6	0.34	0.27 – 0.41	0.59	0.52 – 0.65
	RCP4.5	0.35	0.28 – 0.43	0.67	0.58 – 0.76
	RCP6.0	0.34	0.27 – 0.42	0.68	0.58 – 0.78
	RCP8.5	0.40	0.31 – 0.51	0.88	0.73 – 1.05
Trinidad	RCP2.6	0.38	0.30 – 0.45	0.65	0.58 – 0.73
	RCP4.5	0.39	0.31 – 0.48	0.74	0.64 – 0.84
	RCP6.0	0.38	0.30 – 0.46	0.75	0.64 – 0.87
	RCP8.5	0.45	0.35 – 0.57	0.98	0.81 – 1.170

Summary

Grenada is experiencing sea level rise consistent with regional averages in the Caribbean, which are near the global mean.

Projections for future sea level rise are between 0.27m and 0.57m around 2050. Even though sea level rise is an increasingly daunting problem for Grenada's, its relevance for the preparation of this particular project and Grenada's water sector is comparatively low, because Grenada obtains approx. 90% of its fresh water from precipitation run-off and only approx. 10% from ground water wells (UN-ECLAC 2011, p. 31).

3.6 Conclusion

The available research provides a valuable, preliminary quantitative assessment of climate risks for Grenada. Some projection results are limited in their relevance for this project preparation due to their time scale or robustness.

From the available literature over the region, we arrive at the following conclusions:

- Temperature projections provide robust guidance with clear signals for warming trends.
- Projections on future precipitation also points towards decreasing precipitation trends up to a reasonable level of confidence, robust across all the scenarios.
- Projections on future tropical storms also provide limited guidance, however basing on recent past trends and climate change studies available for the region, a decrease in total but increase in severe storms may be expected.
- Grenada is expected to face a sea level rise of 0.5m and 1m by the mid and end of century respectively.

Table 12: Summary of assumptions for the project preparation

Climate change factor	**Variability**	**Projections**	**Assumptions (2050s)**
Temperature			Increasing trends (+1.16°C to +2.17°C)
Precipitation			Erratic until mid-century, decreasing by up to -20%
Storms			Increase (intensity & frequency)
Sea level rise			Limited relevance for approx. 10% of water production

High confidence

Medium confidence

Low confidence

Temperature projections do provide robust guidance with clear signals for warming trends. Projections on future precipitation provide limited guidance due to low confidence until mid-century (decreasing or increasing trends with a statistical tendency for a decrease). Projections on future tropical storms also provide limited guidance due to low confidence.

When preparing the CREWS project, this VA recommends focusing largely on presently experienced variability and extremes as a departure point when preparing the CREWS project.

4. Vulnerability of Grenada's Water Sector

The IPCC noted for the Caribbean: "concern over the status of freshwater availability has been expressed for at least the past 30 years (IPCC AR5 p. 1622). This concern is due to climate change in conjunction with "economic and management failures in the water sector" (p. 1622). This VA arrived at a similar conclusion for Grenada. The following sections discuss the vulnerability in terms of exposure, sensitivity and adaptive capacity.

4.1 Exposure

Based on (a) the review of Grenada's climate change policies, (b) available research in climate variability and change, and (c) recent GCM data provided by Climate Analytics, this VA assumes the following exposure of the water sector to climatic impacts until the 2050s:

Increasing **temperatures** will have a negative impact on both water production and water demand.

- Water production: Increasing temperatures will increase evapotranspiration, which will have a negative impact on water availability due to a decrease in runoff and stored water.
- Water demand: Increasing temperatures will increase demand from residential users and highly water-dependent economic sectors such as tourism and agriculture.

Decreasing **precipitation** and erratic precipitation will have a net negative impact on water production and water demand:

- Water production: Decreasing precipitation and erratic precipitation are assumed to add to existing difficulties for NAWASA to produce and distribute water to its customers due to:
    - Less available precipitation especially in dry times, assuming approx. 20% decrease in annual mean precipitation by 2050.
    - Interruptions in water distribution due to heavy rainfall events (emergency shut down of water treatment plants in order to protect infrastructure from siltation/clogging)
    - Inability to capture and store sufficient rainwater during high precipitation with existing infrastructure
- Water demand will increase, as erratic rainfall patterns in combination with water supply shortages will incentivize residential and commercial users to increase their own storage capacities for more independence.

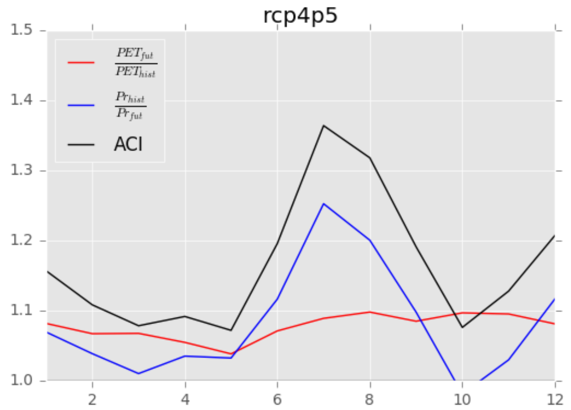
More frequent and intense **storms** will have a negative impact on both water production and water demand:

- Water production: More and stronger storms will add to existing difficulties for NAWASA to produce and distribute water to its users due to:
    - Interruptions in water distribution (shut down of system to protect infrastructure from storms)
    - Inability to capture and store sufficient rainwater during storms with existing infrastructure
    - Damage to infrastructure
- Water demand will increase as storms in combination with water supply shortages will incentivize residential and commercial users to increase their own storage capacities for more independence.

Sea level rise will have a negative impact on ground water production due to salt-water intrusion, because a number of wells in Grenada are within 100 meters to the sea. Overall, the impact will be compounded by Grenada's low dependency on ground water (approx. 10% of total water production).

Figure 10 shows future changes in the aridity of Grenada from CA 2017. The report has further stated that the increased aridity throughout the year points towards considerable impacts on freshwater availability especially at the end of the dry season which generally is the most water stressed time of the year. Furthermore, a marked decrease in aridity, governed by precipitation decrease, at the start of the wet season amplifies this vulnerability of freshwater availability at the end of the dry season."

Figure 10:



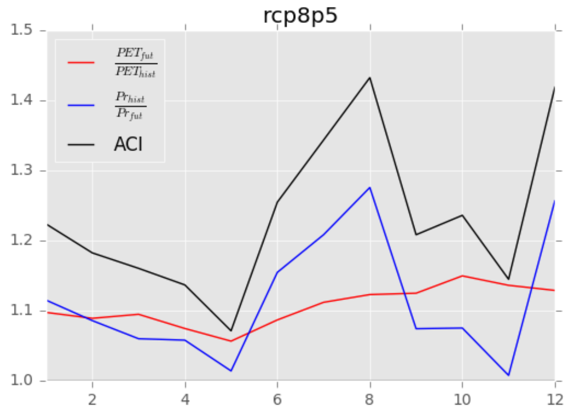


Figure 3: Annual cycle of changes in ACI for 2050, including the contributions of changes in PET and changes in Pr, as compared to historical period. Left and Right panels represent the results for RCP 4.5 and RCP 8.5, respectively

In combination of all impacts, this VA expects a significant negative impact on Grenada's water sector. This is in agreement with general statements by the IPCC AR5 (p. 1622), UN-ECLAC 2011 (p. 83-85), Simpson et al. 2012 (p. 33-36), NASAP 2015, and recent GCM modelling results from Climate Analytics (CA 2017). It is also in agreement with key messages of Grenada's climate change policies and strategies.

Summary: The exposure is assessed as high.

4.2 Sensitivity

Sensitivity is understood as "the degree to which a system is adversely […] affected by a given climate change exposure (GIZ 2014, p. 21)".

Based on (a) the review of Grenada's climate change policies, (b) available research in climate variability and change, (c) recent GCM data provided by Climate Analytics, (d) stakeholder consultations, and (e) other chapters of the Feasibility Study (e. g. 2.3.1 Macroeconomics, 7. Enabling Environment for Climate Resilient Water Users), this VA assumes the following sensitivity of the water sector to climatic impacts until the 2050s:

- Pronounced seasonal variation in water availability
- Heavy reliance on precipitation for water production -> sensitivity to droughts, erratic precipitation patterns, and extreme weather events
- NAWASA systems are sensitive to heavy rainfall events and evapotranspiration
- Highly water-dependent economic sectors (tourism, agriculture)
- Seasonal peak water demand coincides with seasonal peak tourist visits

Summary: Sensitivity is assessed as high.

4.3 Adaptive Capacity

Grenada has some, but comparatively limited experiences in coping with:

- Droughts: the economy took substantial damage in recent droughts including in 2009 (UN-ECLAC 2011, Peters 2015).
- Heavy rainfall: NAWASA has to perform emergency shut downs to prevent damage to its systems from siltation and clogging during heavy rainfall events.
- Sea level rise: NAWASA reported some incidents of salt-water intrusion in its groundwater wells.
- Storms: Shocks**,** such as Ivan in 2004 and Emily in 2005, have demonstrated a disruptive effect on Grenada's population, economy, and government. The estimated damage of the two hurricanes in 2004

and 2005 is approx. 200% of Grenada's GDP. In addition, Grenada's ability to invest in comprehensive climate risk management was seriously compounded. A certain degree of "quick-response" adaptation took place post-Ivan, for example through building codes and re-building better approach. But the recovery of the economic main pillars, tourism and agriculture, took many years and is partly still on-going. The public fiscal space of GoG was exhausted.

- Public finances: Insufficient fiscal management in the past, recent natural disasters, and the depression after the global financial and economic crisis (which affected particularly the tourism sector) led to the tri-island state's inability to service its debt in 2013 and in consequence to a public debt restructuring process aided by the International Monetary Fund's (IMF) Extended Credit Facility Support Programme.
- Human development: Grenada's Human Development Index value for 2015 was 0.754, which puts the country in the high human development category positioning at rank 79 out of 188 countries and territories. The rank is shared with Brazil. This constitutes a good general basis for adaptive capacity among the population.

Summary: While Grenada's general adaptive capacity is assessed as medium. The water sector's adaptive capacity is assessed as medium to low due to financial constraints and a limited track record of systemic change in response to external shocks.

4.4 Conclusion

In general, vulnerability is understood as a relationship between exposure, sensitivity and adaptive capacity (GIZ 2017, IPCC 2007 AR4 WG2).

Grenada's water sector's exposure was assessed as high, sensitivity as high, and adaptive capacity as medium to low.

In summary, the water sector's vulnerability is assessed as **medium with a trend towards high**.

This is in agreement with vulnerability indices, for example:

- The Notre Dame Global Adaptation Index lists Grenada at rank 61 with a declining trend (down from rank 43 in 1995)[3].
- Standard and Poor's Global Market Intelligence assessed Grenada's vulnerability at rank 96 of 116.[4]

It is important to note that Grenada's water sector is less exposed to slow-onset impacts such as sea level rise, but highly exposed and sensitive to shock-like climate impacts linked to hurricanes, droughts and heavy rainfall. These impacts are already a daunting reality in Grenada today and are likely to be aggravated further by climate change in the coming decades. They are particularly difficult to manage because they materialize as sudden shocks to the population, public services, and economy. They are also more difficult to project in GCMs.

Taking all this into consideration, this VA:

- **Confirms the vulnerability of Grenada's water sector and sufficient evidence for justifying the preparation of a GCF Funding Proposal with high relevance against the Funds investment criteria 'impact potential'.**
- **Recommends taking decisive action as soon as possible. The UNFCCC'S Article 3 Principle 3 (UNFCCC 1992) is very relevant for Grenada. The government and the international community should cooperate in order to mitigate serious harm caused by insufficient water availability in the near future. There is no need to wait for better scientific certainty.**

[3] http://index.gain.org/country/grenada

[4] S&P Global Market Intelligence Global Credit Portal: available online at goo.gl/FvwmFG

5. Theory of Change and Suggestions for a Logic Framework

This section presents a:

- Basic quantitative model for Grenada's water sector taking climate change into account
- Theory of Change for the CREWs project and recommendations for the logic framework
- Recommendations for priority resilience-enhancing actions

5.1 Basic Quantitative Model

The assessments above confirmed the complex relationship of climate variability and climate change impacts with observed exposures, sensitivities and adaptive capacities in Grenada's water sector. In order to avoid critical water shortages in the future, the water sector has to both (a) reduce its water demand and (b) increase its water supply to levels that are resilient to both observed climate variability and expected future climate change. This is in agreement with recommendations in Grenada's climate policies, such as the NAP 2017 draft, in reviewed studies such as UN-ECLAC 2011, Simpson et al. 2012, and NASAP 2015 draft, and also confirmed by an additional consultation of a recent ensemble of GCMs from CMIP5.

However, in order to prepare the project, the degree or severity of future climate impacts need to be better understood and quantified as far as possible to provide guidance for designing activities and budgets.

A model is needed in order to identify quantifiable targets for "resilient levels" of water supply and demand. This model needs to:

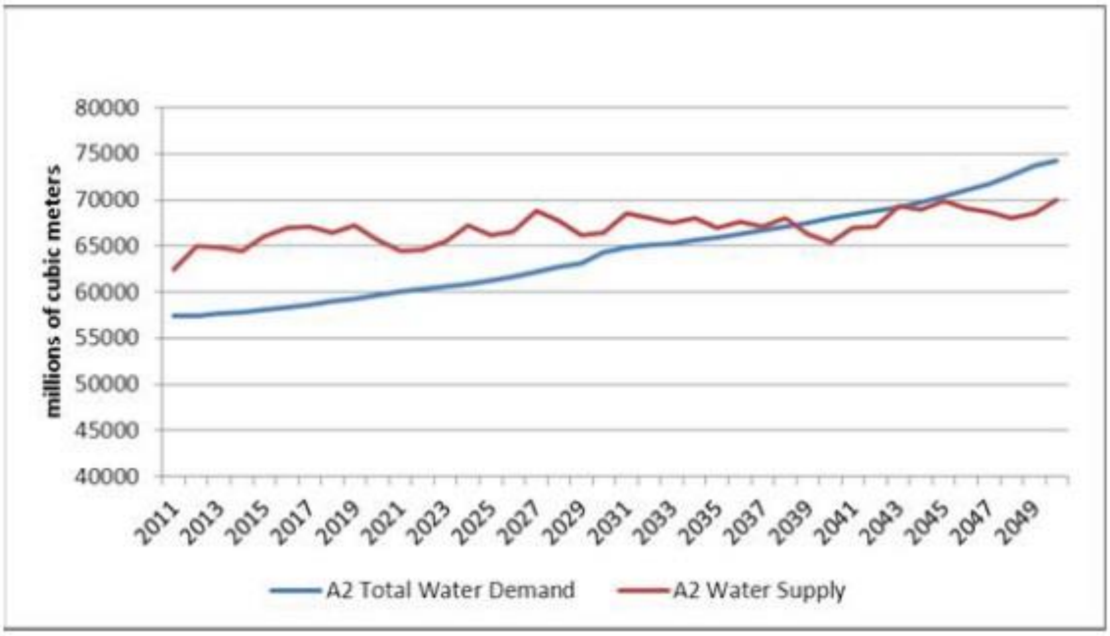
- Adequately represent water supply and demand on Grenada mainland
- Take climate variability and change into account on a time scale that reflects the expected physical and economic lifecycle of the projects outputs (e. g. technology and infrastructures).
- Identify critical quantifiable reference points for the project

Example

UN-ECLAC 2011 attempted at developing such a model (see UN-ECLAC p. 51). According to the UN-ECLAC model, when using the (outdated) IPCC SRES scenario A2, water supply would become insufficient to meet demand in the 2030s. In other scenarios, the water demands would be met throughout the 21st century.

Figure 11:

Figure 27: A2 Water Needs 2011 to 2050



Source: Compiled by author

There were challenges within the UN-ECLAC model, which unfortunately limit its usefulness for preparing this GCF project. The model applies dated SRES scenarios, which assume unrealistic population growth rates for Grenada. It also assumes declining numbers of tourists visiting Grenada. Recent figures of Grenada's Tourism Association disproved this assumption by showing a solid growth in visitor arrivals of 12.7% and stayover arrivals of 5.4% in 2015.[5] There also seem to be inconsistencies with the model's water production data.

General assumptions for a new model

The following general assumptions were applied for building a basic quantitative model.

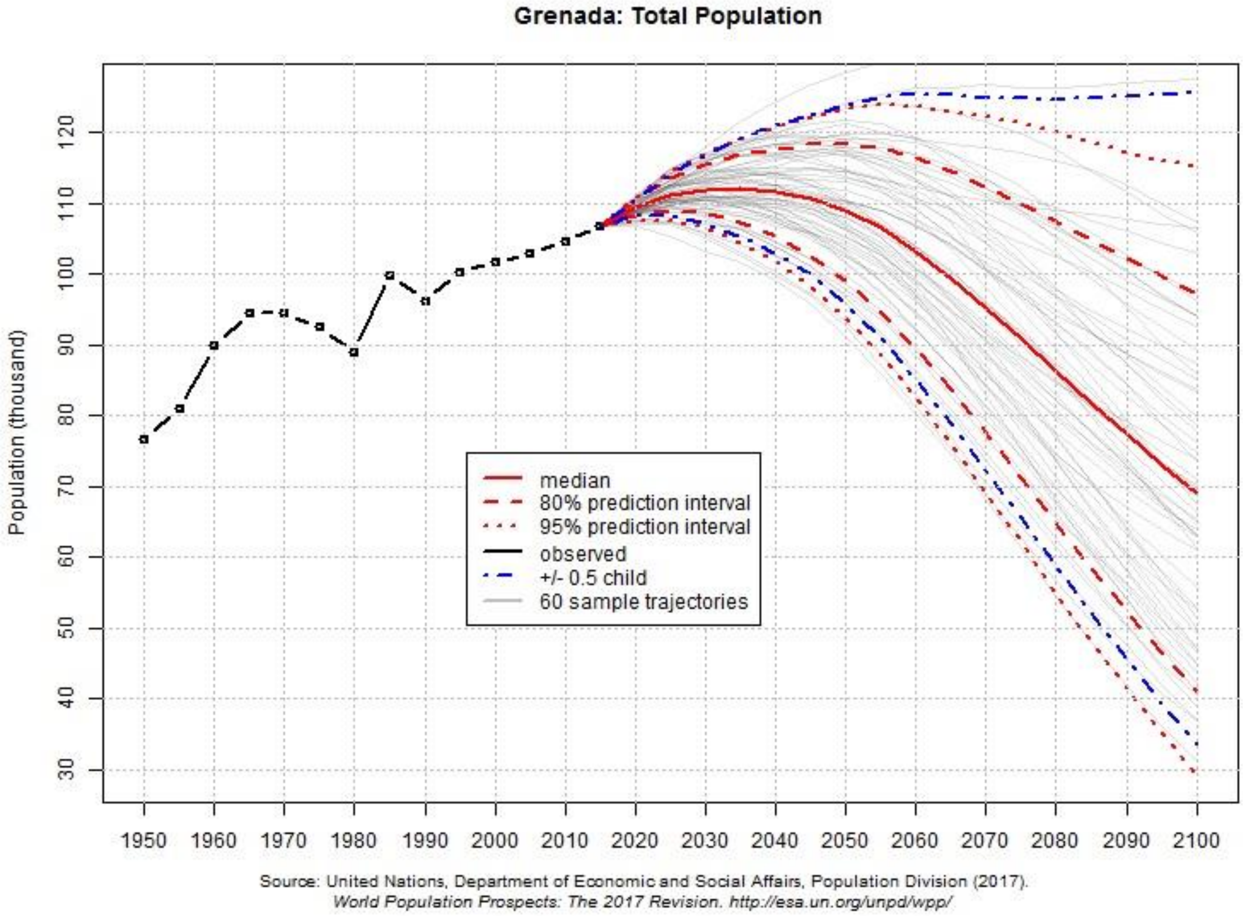
Population:

Population growth rates are assumed to continue to be low. Grenada's expected total population in the 2050s is around 110,000 according to the United Nations.[6] This would represent approx. 5% of population growth compared to the present day.

[5] http://www.grenadagrenadines.com/news/visitor-arrivals-to-grenada-increased-by-12.7-in-2015/

[6] http://worldpopulationreview.com/countries/grenada-population/

Figure 12:



Precipitation:

This study assumes that declining precipitation will have the highest impact on the water sector, because 90% of water on Grenada mainland is collected from rainwater. The latest projections (CA 2017) suggest a mean annual decrease of up to 20% until the 2050s with seasonal declines of up to 40% in JJA (see 3.2.5 Results above). CA (2017) also points towards an increase in annual aridity of about 20% over Grenada for both RCP 4.5 and RCP 8.5 scenarios, with the highest increase of 40% for the month of August in RCP 8.5.

Table 12:

		Precipitation Min	Median	Max
		% Change		
annual	RCP4.5	-14.56	-6.41	-2.43
	RCP8.5	-21.69	-9.64	1.87
DJF	RCP4.5	-23.74	-3.97	-3.65
	RCP8.5	-36.54	-13.84	6.15
MAM	RCP4.5	-11.26	-5.31	7.38
	RCP8.5	-24.88	1.57	11.45
JJA	RCP4.5	-40.52	-19.05	5.96
	RCP8.5	-41.82	-16.17	12.22
SON	RCP4.5	-12.25	-3.61	14.01
	RCP8.5	-10.44	-6.79	7.18

Using the year 2009 as a proxy:

The ‘new climate normal’ for Grenada’s 2050s with less rain is assumed comparable to the 2009 (and 2010) drought conditions. The model can therefore use NAWASA data from 2009 to represent water availability in Grenada in the 2050s. However, some clarifications are necessary. The year 2009 saw precipitation decline by 37% compared to annual average rainfall at Grenada mainland's only weather station at the low-lying Maurice Bishop International Airport at the far southeast of the island. These readings were probably extremes due to the specific location of the airport and would be higher than projections indicate. NAWASA water production data is a better proxy for Grenada mainland and suggest a decrease in precipitation at its catchments in higher altitudes of approximately 20% compared to annual averages. This may be comparable with projections for 2050 (CA 2017).

Table 13 (from NAWASA data):

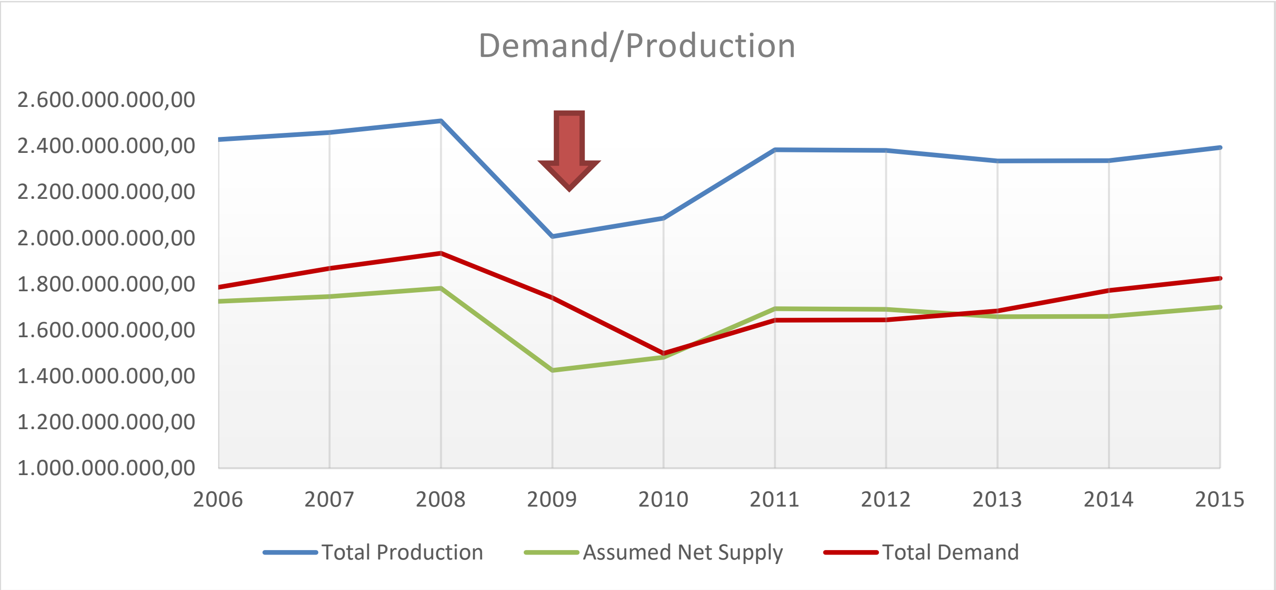
	Total Demand*	**Total Production***
2016	1.824.836.545,40	2.455.240.000,00
2015	1.772.902.836,13	2.393.930.000,00
2014	1.683.547.440,70	2.337.149.000,00
2013	1.644.370.116,05	2.335.840.000,00
2012	1.643.175.908,91	2.381.500.000,00
2011	1.642.107.292,00	2.384.510.000,00
2010	1.740.189.531,72	2.087.235.000,00
2009	1.934.376.234,00	2.007.120.000,00
2008	1.869.046.897,00	2.510.000.000,00
2007	1.786.563.937,00	2.460.000.000,00

*Imperial gallons

The data shows that due to the drought, water production went down by almost 20%. The discrepancy between 37% decrease in rainfall at the airport and approx. 20% decrease in water production can be explained by more rainfall usually occurring in higher locations on Grenada mainland and because 10% of the water production comes from groundwater wells. Therefore, the assumption is that in 2009 Grenada mainland experienced a precipitation decline of approx. 20%, which would be comparable to the new climate normal projected for 2050.

Interpretation of 2009 data and impact on water availability

Figure 13: A basic model of the 2009 drought



In general, NAWASA data shows that net water supply and water demand leave virtually no room for droughts or other shocks. In 2009, total water demand (red) came close to 2 billion imperial gallons. Gross total water production (blue) fell to just above 2 billion imperial gallons in 2009. With assumed 29% real water loss due to inefficiencies in the systems, the actual net supply of water (green) fell under an estimated 1.5 billion imperial gallons.

The estimate for the resulting deficit in water availability is over **25% of total water demand on Grenada mainland** that NAWAS could not meet.

The human and economic impacts of the 2009 drought were substantial. Stakeholder reported about water outages across the island. A recent study (Peters 2015) described the substantial social harm and economic losses the drought caused in Grenada.

All additional quantitative assumptions for the model are summarized in Table 14 below.

Basic quantitative model for climate resilient levels of water production and demand in 2050

Table 14: Quantitative assumptions and model results

Assumptions/model results	Value	Unit	Reference
Total population in Grenada in 2050	110000,0	People	UN
Total population of Carriacou and Petite Martinique	6521,0	People	GoG
Population on Grenada mainland connected to NAWASA systems in 2050	101409,4	People	UN, GoG, NAWASA
Water demand in 2009 drought condition	165,0	Liter per person per day	NAWASA
Resilient level of water demand (-18% compared to 2009)	135,0	Liter per person per day	NAWASA
Water demand from private sector in 2009 drought conditions	459,8	Imperial gallons (millions)	NAWASA
Water demand from public sector in 2009 drought conditions	209,1	Imperial gallons (millions)	NAWASA
Demand elasticity in 2009 drought condition (comparable to 2050 new climate normal)	10,0	Percent (%)	
Resilient level of total water demand in Grenada mainland (-18% compared to 2009)	1647,7	Imperial gallons (millions)	
	7,5	Cubic meters (m3) (millions)	
Contingency for other climate change impacts (for example evapotranspiration)	100,0	Imperial gallons (millions)	
Water production of NAWASA systems in 2009 drough conditions	2007,1	Imperial gallons (millions)	
Real water losses in NAWASA distribution systems (average 2005-2015)	29,0	Percent (%)	
Improved real water losses without GCF project support (average in 2025)	25,0	Percent (%)	
Resilient level of real water losses in NAWASA distribution systems	19,0	Percent (%)	
Resilient level of net water production	1912,4	Imperial gallons (millions)	
	8,7	Cubic meters (m3) (millions)	
- to meet resilient level of demand on Grenada mainland			
- after resilient level of real water losses in NAWASA distribution systems			
- incl. 10% demand elasticity for peak demand due to droughts/extremes/disasters			
- incl. contingency excess water prodution to account for other climate impacts such as evapotranspiration			
Resilient level of gross water production on Grenada mainland before losses	2361,0	Imperial gallons (millions)	
	10,7	Cubic meters (m3) (millions)	
Additional water production capacity needs	353,9	Imperial gallons (millions)	
	1,6	Cubic meters (m3) (millions)	

The model helps to determine estimates for a resilient level of water supply in conjunction with resilient water demand for Grenada in the year 2050. Due to the limited availability of data and research, this simple model has to rely on certain assumptions and sometimes rather coarse data. **It should not be understood as a precise instrument, but rather an approximation that can provide initial broad reference values for the project**.

In order to meet future water demand in 2050, net water supply after losses would have to meet anticipated demand and account for appropriate excess supply to cope with variability, extremes, disasters and climate impacts that could not be integrated in the model such as evapotranspiration.

BAU vs. project impact

Figure 15:

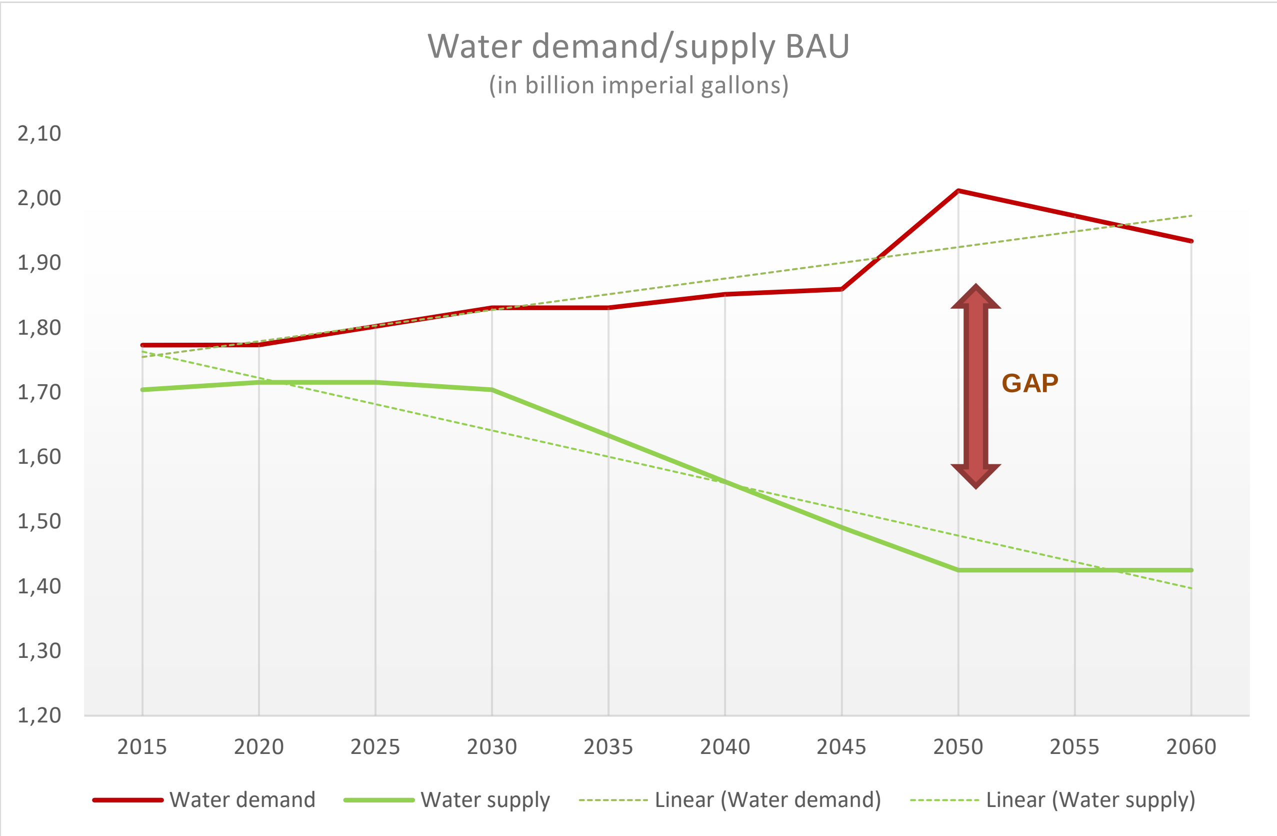
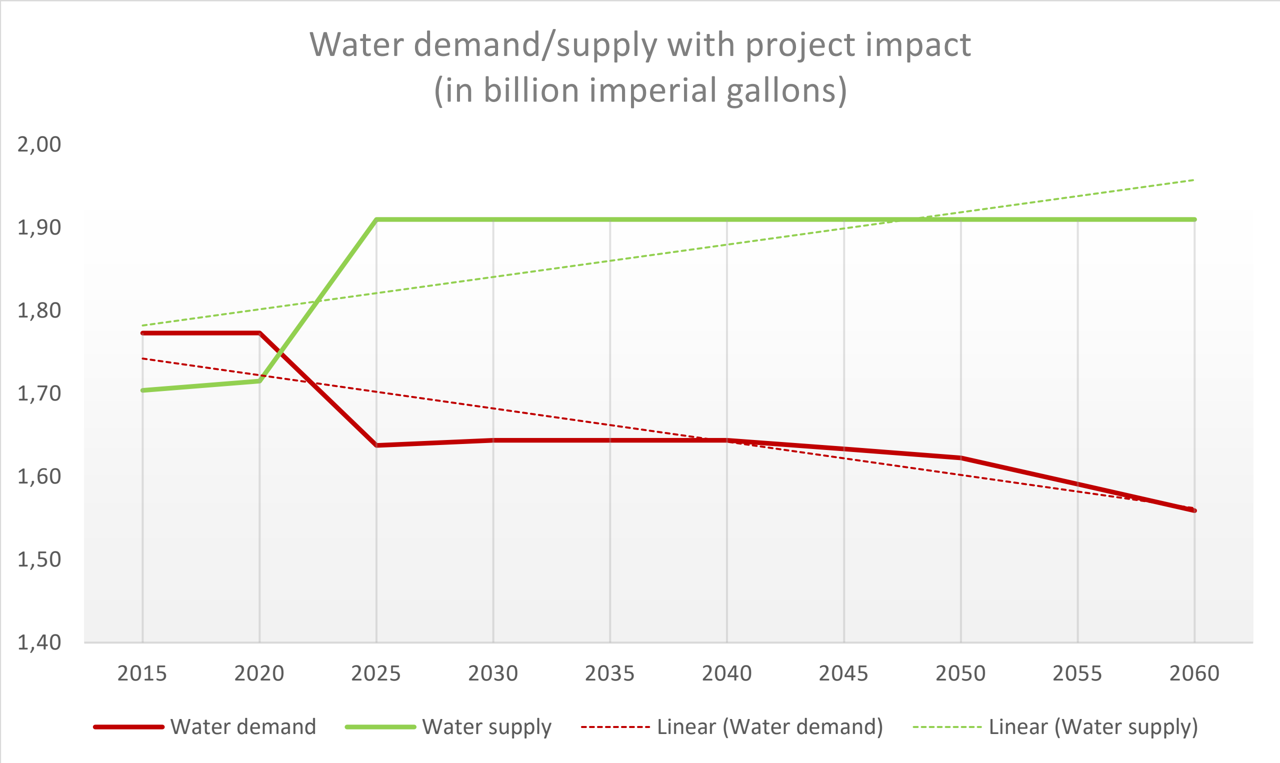


Figure 16:



Taking all this into account, a climate resilient water sector in Grenada in 2050 would rely on a NAWASA system producing approx. 2.36 billion imperial gallons before real losses under the drier “new climate normal” conditions of the year 2050 with approximately 20% less rainfall on average.

NAWASA would then supply **1.91 billion imperial gallons after 19% of real water losses to a population of 110,000 people demanding approx. 135 liters per person per day as well as businesses and public sector, with both having reduced their water demand by 18% compared to 2009 levels**. **Approx. 291 million imperial gallons of excess water and sufficient storage capacity would allow for temporary peaks in demand due to extreme events or disasters such as droughts or storms.**

Compared to 2009 water production before real losses, NAWASA would have to raise its water production capacity by approximately **354 million imperial gallons** – mainly through upgrades of existing systems. This will require substantial engineering inputs.

Necessary efficiency gains of 18% less in per person per day water demand, demand from the private sector, and demand from the public sector, as well as 10% reduction in real water loss in NAWASA systems are ambitious but realistic achievable targets, according to water engineers and experts that GIZ consulted during stakeholder consultations on-island. This will require comprehensive improvements in the regulatory framework for the water sector, fiscal incentives for diverse stakeholders (households, different kinds of businesses, especially tourism and agriculture, and the public sector) and highly effective communication and awareness raising campaigns.

5.2 Recommendations for priority actions to enhance resilience

In summary, this VA confirms the initial concept of the CREWS GCF project and recommends the following priorities for actions:

High direct impact actions:

- Increasing NAWASA rainwater-fed water production
- Resilient ground water production (wells)
- Resilient water treatment facilities (silt traps and river intake retrofits)

- Reducing distribution inefficiencies and real water losses
- Increased decentralized potable water storage facilities
- Increasing water use efficiencies with households, businesses, especially tourism and agriculture, and the public sector

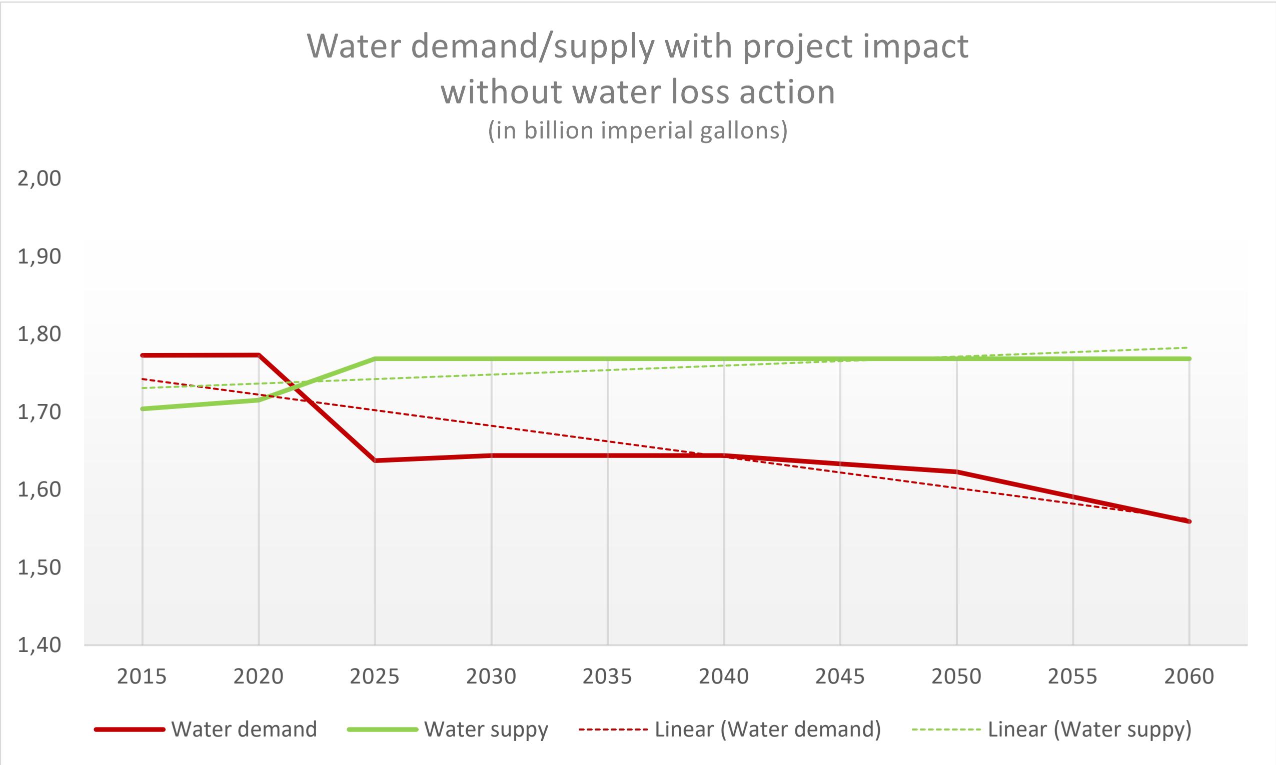
High indirect impact actions (enabling environment):

- Mainstreaming climate resilient water management in relevant policies
- Climate-sensitive water tariffs
- Introducing a Water Management Unit with climate change competencies
- Sustainable management of watersheds and catchments
- Climate and water data generation
- Regulation (for example building codes)
- Incentives (for example tax breaks)
- Communication and awareness raising campaigns

All of the recommendations are in agreement with Grenada's NAP and other VAs, for example UN-ECLAC 2011 pp. 67-72, NASAP 2015 pp. 164-179, and recently HR Wallingford 2017 pp. 36-38.

We understand, however, that current GCF policies and practices may not allow the Fund to support water loss activities because of additionality concerns (NAWASA will have to replace leaking pipes, which leak due to age and not climate change). The GCF therefore requested a second project impact scenario excluding activities for reducing water loss. For this scenario, we assumed that Grenada will manage to reduce real water losses from currently approx. 29% to 25% until the year 2025 through some own investments and with the support of other donors.

Figure 17:



This project impact scenario would still represent a paradigm shift in the water sector, but would leave considerably less excess water to cope with extremes and shocks (approx. 145 billion imperial gallons).

5.3 Theory of Change and recommendations for the logic framework

To achieve resilient levels of water demand and water supply, the sector would have to undergo a comprehensive transformation on multiple levels. In GCF terminology, this would be considered a "paradigm shift". The paradigm shift in Grenada's water sector would need the participation of citizens and businesses, the public sector as provider of water and infrastructure, and behavioral change triggered through appropriate governance, regulation, incentives and awareness raising.

Suggested project objective: **Increased systemic climate change resilience in Grenada's water sector**

Suggested outcomes:

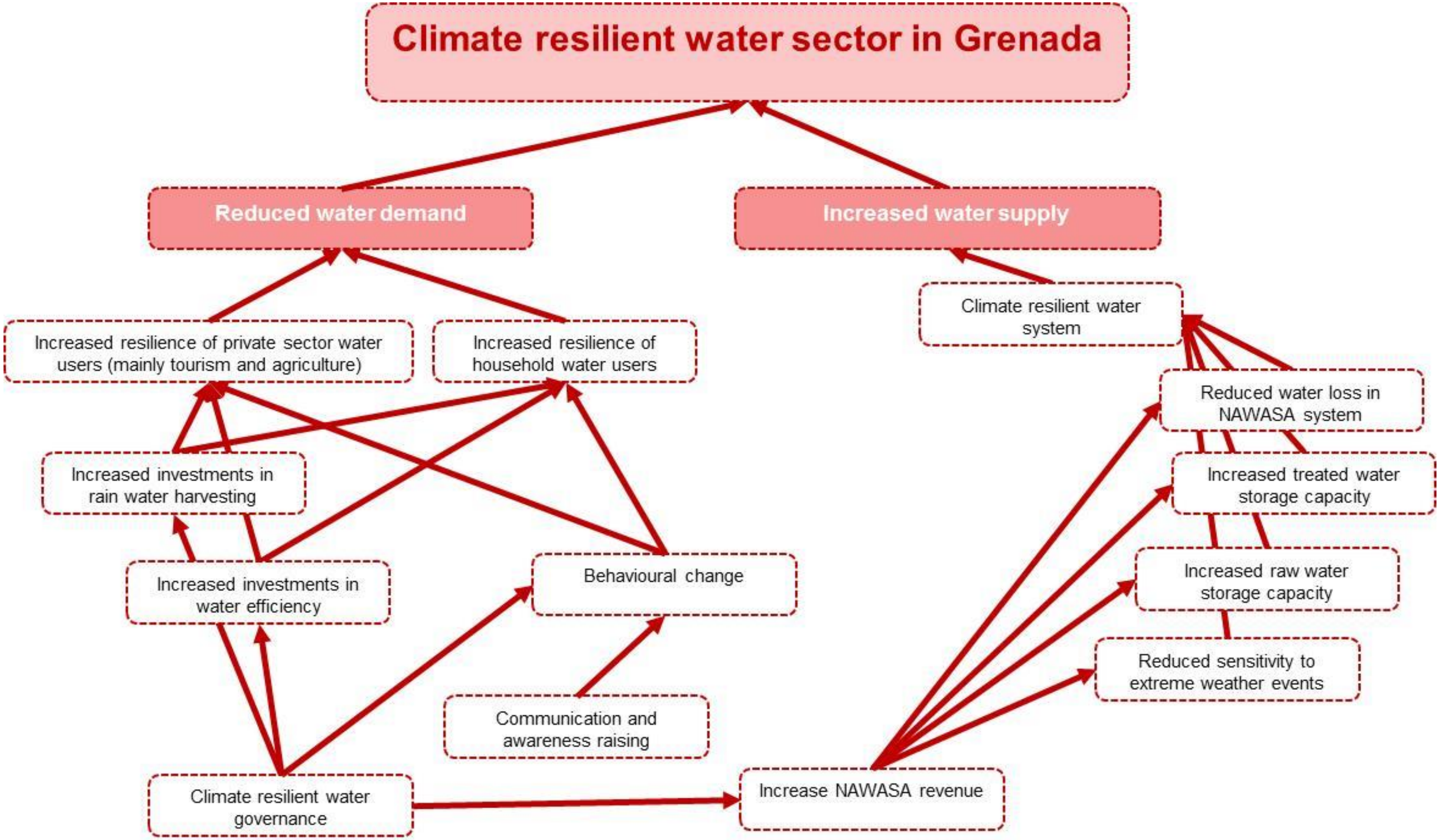
- Outcome 1: Resilient governance and institutions
- Outcome 2: Resilient water users
- Outcome 3: Resilient water supply systems.

Suggested key indicators based on model results:

- Water demand (per capita per day) reduced to climate resilient levels , baseline: 165 liters, target: 135 liter (-18)
- NAWASA annual water production before losses is increased to anticipate climate resilient levels, baseline 2.41 billion imperial gallons (average 2005-1016), target: 2.77 billion imperial gallons (this reflects an increase of 354 million imperial gallons and the necessary added capacity for a climate resilient production)
- Total annual water production after losses is increased to climate resilient levels baseline 29%, target: 19%

The relationship of these outcomes with climate change impacts as well as exposures, sensitivities and adaptive capacities in Grenada's water sector is illustrated in the figure below:

Figure 18: Basic Theory of Change for a climate resilient water sector in Grenada:



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Annex I: Future Climate Projections over Grenada using CMIP5 GCMs

Presented by Climate Analytics to GIZ on 4 July 2017 by Fahad Saeed, Laetitia De Marez, Carl-Friedrich Schleussner, and Michiel Schaeffer

Background:

GIZ is preparing a GCF Funding Proposal for increasing the resilience of Grenada's water sector. The body of available research on climate change impacts on Grenada is small and partly outdated. In order to benefit from recent advances in climate science, to overcome the limitations of available older research on climate impacts in Grenada, and to cross-check the findings of GIZ's Vulnerability Assessment, GIZ comissioned the climate services consultancy firm Climate Analytics to produce this report based on updated GCM projections.

Abstract

A Global Climate Model (GCM) ensemble, comprising of five GCMs from Coupled Model Inter-comparison Project (CMIP5) used for IPCC's fifth assessment report (AR5), has been employed to assess the future climate changes over Grenada. GCMs have done a satisfactory job in capturing annual cycles of temperature and precipitation. The projections based on RCP 4.5 and RCP 8.5 scenarios show a marked increase and decrease in temperature and precipitation for the middle of 21st century respectively, at annual as well as seasonal time scales. The extremes associated with these variables are also projected to intensify in similar direction. Further our analysis show that Grenada is likely to experience increase in aridity throughout the year, which would have serious consequences for the availability freshwater resources in the future. Our results call for serious adaptation measure to be taken to reduce to vulnerability of people of Grenada to the adverse impacts of climate change.

Introduction

According to the UN estimates, the total population of Small Island Developing States (SIDS) is estimated to be 66 million, which is expected to rise 82 million by 2040[7] (UN 2013/14). With almost zero contribution to the global Green House Gas (GHG) emissions, the population of SIDS is considered to be extremely vulnerable to the adverse impacts of climate change. Main threats to SIDS associated with changing climate include sea-level rise, cyclones, increasing air and sea surface temperatures, and changing rainfall patterns. In the wake of these threats, SIDS are likely to face loss of adaptive capacity and ecosystem services that are critical to their lives and livelihoods (Nurse et al. 2014).

An impact that gets often overlooked when studying the vulnerability of SIDS is related freshwater availability. The freshwater lens of SIDS is often rather small and can be depleted rapidly during drought conditions (Holding 2016). In addition, subtropical regions like the Caribbean are projected to experience an increase in drought conditions already at warming levels of 1.5°C (Schleussner et al. 2016). In a recent study, Karnauskas et al. (2016) found robust tendency towards increasing aridity over SIDS affecting 16 million people by the end of the century. According to this study, Lesser Antilles is one of the regions, which are projected to experience severe future freshwater stress.

Grenada, with a total population estimate of around 0.1 million, is one of the sovereign states of the Lesser Antilles, and hence highly vulnerable according to the findings of Karnauskas et al. (2016). According to the observed data, Grenada has already been experiencing changes in climatic parameter with increasing temperature along with variability in rainfall throughout the year, particularly during the

7 http://www.un.org/en/development/desa/population/publications/pdf/technical/TP2013-4.pdf

wet season in the latter half of the year (Simpson et al. 2012). In addition, Grenada is also susceptible to tropical cyclonic activity, with historical trend suggesting an increase in the number of hurricanes making landfall in Grenada (NASAP, 2015). Similar to all the SIDS, Grenada is also vulnerable to the sea level rise with many stations in the Caribbean suggesting an upward trend (Simpson et al., 2012). These multi-faceted impacts due to climate change faced by Grenada are likely to become more pronounced in future. Hence it calls for a better estimate of future vulnerability assessment of Grenada's climate based on recent data.

Today climate models or more specifically global climate models (GCMs) are considered to be the most sophisticated tools to carry out projections for future climate. These GCMs served as the backbone of the Intergovernmental Panel on Climate Change (IPCC) Assessment Reports (ARs) for the last couple of decades. These GCMs are run with the scenarios assumption to make predictions. In a strict sense, these scenarios are not predictions or forecasts; rather they are image of futures. These scenarios try to capture a range of predictions of future climate change based on a range of ways that humans may live, interact, behave, work, and populate the Earth in the future. IPCC's Special Report on Emission Scenarios served as the basis for AR4 published in 2007. These scenarios are generally referred as SRES scenarios. Since the AR4, important improvements in the models in GCMs were made, and hence these improved/advanced models dictate the need for the new detailed scenarios[8]. Therefore, it resulted in the development of new scenarios called Representative Construction Pathways (RCP). IPCC's AR5 is mainly based on RCPs, which are used to run more advanced/improved GCMs.

For Grenada, there have been a couple of studies, which presented the analysis based on climate modeling data (e.g. Simpson et al. 2012). However, all these studies are based on AR4 GCMs, which used old SRES scenarios. With the availability of advanced GCMs and new scenarios, there is a need to carry out similar analysis over Grenada using the recent GCM data run with new scenarios. Therefore, in the present study, results of future projections based on AR5 GCMs using RCP scenarios are presented. It is well established that the projections based on climate models is vulnerable to many uncertainties intrinsically involved in the system. Therefore, in order to minimize the element of uncertainties, either from representation of GHGs emissions or the intrinsic processes of the climate models themselves, the use of multi-model multi-scenario ensemble is one of the procedures and essential to do before utilization of the model projections. Hence in this study, we have adopted this approach and its details are presented in the following section.

Data and Methodology

The data used in this study has been obtained from the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP[9]) which is a community-driven modelling initiative bringing together impact models across sectors and scales to create consistent and comprehensive projections of the impacts of different levels of global warming. Before feeding the GCM data as an input to impact models, the daily data from the following five CMIP5 Global Climate Models (GCMs) i.e. GFDL-ESM2M, HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM and NorESM1-M has been bias corrected. The details of the bias correction methods have been presented in Hempel et al. (2013). Furthermore, in order to assess the performance of GCMs, the EWEMBI dataset has been used in this study as a proxy for observation (Lange 2015).

A substantial advantage of using ISIMIP GCMs is that the data is available at 0.5 degree. Therefore, the Grenada main island is represented in this dataset, which is generally not represented in a standard GCM grid due to its coarser resolution. The results presented in the following section are over this one grid. Besides using multiple GCMs, we have also based our analysis on two RCP scenarios namely RCP 4.5 and RCP 8.5 representing the middle-of-the-road and business-as-usual scenarios, respectively. Moreover, time periods from 1971 to 2000 and 2036 to 2065 are considered for the representation of historical and future period respectively. The RCP framework used in the IPCC AR5

[8] https://www.sei-international.org/mediamanager/documents/A-guide-to-RCPs.pdf

[9] https://www.isimip.org

is a purely greenhouse gas concentration based scenario framework, unlike the older SRES approach that included narratives of future socio-economic development. The RCPs are thereby independent of assumptions for these indicators.

Aridity Change Index (ACI) has been calculated after Karnauskas (2016) defined as a ratio of the fractional change in potential evapotranspiration (PET) to the fractional change in precipitation (Pr): $ACI=(PET_F/PET_H)/(Pr_F/Pr_H)$, where subscript F indicates future, and subscript H indicates historical. The values of PET have been calculated after Allen et al. (1998).

Results

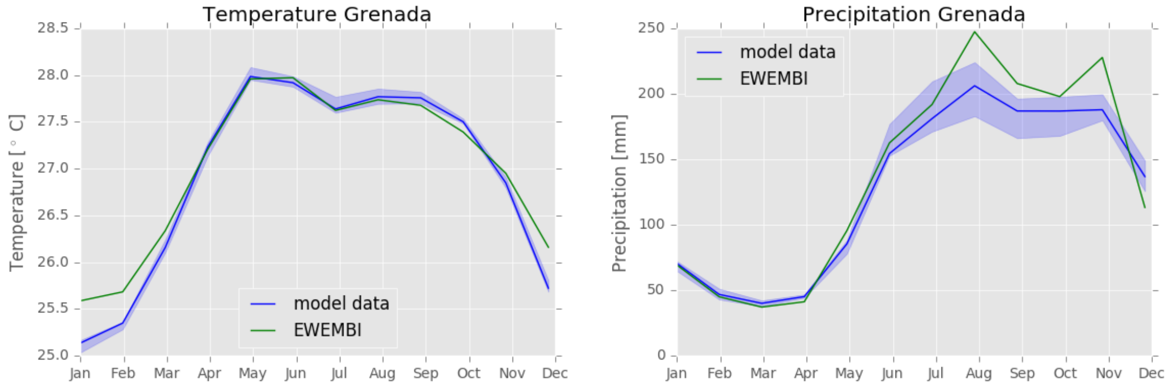

Figure 1: Annual cycle for Precipitation and Temperature over Grenada. Blue and Green curves represent GCM ensemble median and EWEMBI respectively, whereas the light blue band represent the inter-model spread of the GCM ensemble. Both the curves represent the time period from 1971-2000.

Figure 1 shows results of performance of GCMs in capturing the annual cycle of precipitation and temperature. Although certain differences still remain such as the underestimation of precipitation during wet season, the models have done a very reasonable job in capturing the seasonality of precipitation and temperature. For precipitation, the narrow band of inter-model spread shows higher agreement among the models for the dry period, which becomes wider for the wet period. However, the EWEMBI curve generally remains within the inter-model spread. Opposite behavior can be seen for the case of temperature in Figure 1 in which there is a general agreement during the wet period and a cold bias during the dry period. However, this bias is quite small (less than 0.5°) with inter-model spread for temperature showing large agreement among the GCMs (narrow spread) as compared to precipitation.

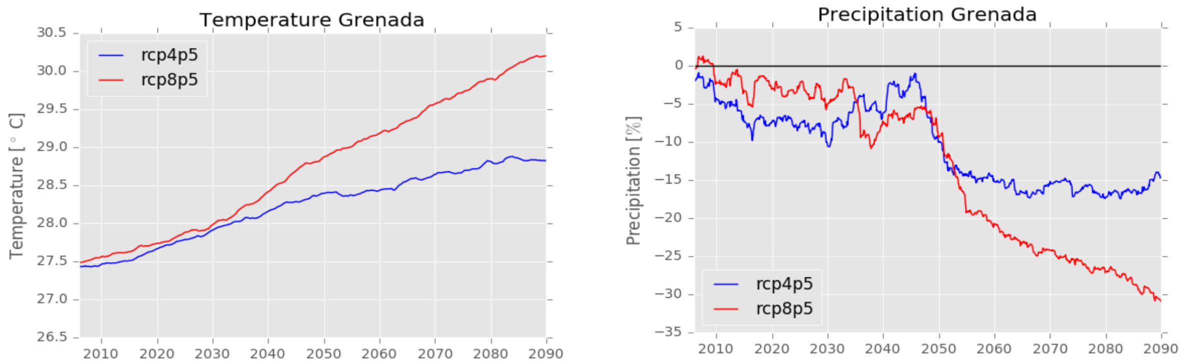

Figure 2: Future evolution of temperature and precipitation over Grenada for RCP8.5 (red curves) and RCP4.5 (blue curves). Both the curves show median values of five-member ensemble which have been plotted by taking the running mean of 30 year timestep

		Temperature		
		Min	Median	Max
		Change in °C		
annual	RCP4.5	1.16	1.44	1.59
	RCP8.5	1.41	1.98	2.17
DJF	RCP4.5	1.14	1.47	1.52
	RCP8.5	1.38	1.91	2.07
MAM	RCP4.5	1.11	1.37	1.42
	RCP8.5	1.28	1.79	1.95
JJA	RCP4.5	1.22	1.54	1.73
	RCP8.5	1.46	1.92	2.31
SON	RCP4.5	1.19	1.65	1.77
	RCP8.5	1.52	2.16	2.38

		Precipitation		
		Min	Median	Max
		% Change		
annual	RCP4.5	-14.56	-6.41	-2.43
	RCP8.5	-21.69	-9.64	1.87
DJF	RCP4.5	-23.74	-3.97	-3.65
	RCP8.5	-36.54	-13.84	6.15
MAM	RCP4.5	-11.26	-5.31	7.38
	RCP8.5	-24.88	1.57	11.45
JJA	RCP4.5	-40.52	-19.05	5.96
	RCP8.5	-41.82	-16.17	12.22
SON	RCP4.5	-12.25	-3.61	14.01
	RCP8.5	-10.44	-6.79	7.18

Table 1: GCM projected changes of Temperature and Precipitation for Grenada between the future and historical periods. Time periods from 2036 to 2065 (centred at 2050) and 2071-2000 have been taken as future and base periods respectively.

Future evolution of temperature and precipitation is presented in Figure 2 for RCP4.5 and RCP8.5 scenarios, indicative of gradual increase and decrease of temperature and precipitation respectively, till the end of 21st century. Interestingly, RCP4.5 shows a decrease in precipitation more than RCP8.5 in the first half of 21st century. However, precipitation decrease in RCP8.5 surpassed RCP4.5 in the latter half of the 21st century. These changes are further explained in Table 1 which show annual as well as seasonal changes between future and historical periods centered at 2050. The temperature projections indicate that Grenada can be expected to warm by 1.16°C to 1.59°C and 1.41°C to 2.17° by 2050 at annual time scale for RCP4.5 and RCP8.5 respectively. At seasonal time scale, the maximum temperature increase is expected to occur for SON projecting a median increase of 1.65°C and 2.16°C for RCP4.5 and RCP8.5 respectively. Moreover, it can be inferred from Table 2 that although the future precipitation for Grenada span both overall increase and decrease, but heavily tend towards decrease in most models. Median values at annual as well as seasonal time-scale (except from MAM for RCP8.5) represent decrease in precipitation. Projected changes in annual rainfall range from -14.56% to -2.43% and -21.69% to 1.87% for RCP 4.5 and RCP 8.5 respectively. The largest decrease in precipitation is projected for the wet months of JJA with the median values of -19.05% and -16.17% for RCP 4.5 and RCP 8.5 respectively.

		Frequency of hot days (TX90P)			Frequency of hot nights (TN90P)			Hot Extremes (TXx)		
		Min	Median	Max	Min	Median	Max	Min	Median	Max
		Future % frequency			Future % frequency			Change in $°C$		
annual	RCP4.5	56	60	75	59	77	90	1.2	1.5	1.7
	RCP8.5	65	76	86	66	86	96	1.7	2.2	2.4
DJF	RCP4.5	56	58	74	60	81	89	1.2	1.4	1.6
	RCP8.5	63	74	80	67	89	96	1.6	2.1	2.1
MAM	RCP4.5	32	54	65	51	70	88	1.1	1.2	1.5
	RCP8.5	52	71	76	57	80	96	1.4	1.8	2.3
JJA	RCP4.5	59	69	86	65	78	92	1.1	1.6	1.7
	RCP8.5	68	80	94	70	86	97	1.6	2.1	2.6
SON	RCP4.5	58	67	84	62	71	92	1.3	1.5	2.0
	RCP8.5	69	86	93	70	83	97	2.0	2.3	2.7

Table 2: GCM projected changes in extreme temperature for Grenada between the future and historical periods. Time periods from 2036 to 2065 (centered at 2050) and 2071-2000 have been taken as future and base periods respectively.

Table 2 show extremes values for temperature and precipitation respectively. Projections indicate increases in the frequency of hot days by 56% to 86% of days annually and hot nights by 59% to 96% of nights annually by 2050. The rate of increase in these extremes varies largely among models for each scenario; however it remains similar throughout the year. Moreover, Table 2 also indicates an increase in hot extremes throughout the year with the largest increases occurring in the months of SON projecting an increase in the range of 1.3°C to 2.7°C. Projections for precipitation extremes are mixed across the models, ranging from decreases and increases of all indicators of extreme rainfall. However, as can be seen from Table 3, there is a higher tendency towards the decrease in rainfall even during the extreme events, especially for the case of RX1day showing negative values for the median at annual as well seasonal time scales.

		Maximum 1-day rainfall (RX1day)			Maximum 5-day Rainfall (RX5day)		
		Min	Median	Max	Min	Median	Max
		Change in mm			Change in mm		
annual	RCP4.5	-2	-1	2	-6	0	4
	RCP8.5	-15	-11	1	-25	0	4
DJF	RCP4.5	-4	-1	0	-6	-1	0
	RCP8.5	-9	-5	2	-15	-5	3
MAM	RCP4.5	-1	-1	0	-2	2	2
	RCP8.5	-5	-2	5	-10	8	9
JJA	RCP4.5	-10	-3	9	-24	8	8
	RCP8.5	-38	-18	0	-63	-23	10
SON	RCP4.5	-5	-1	9	-5	7	25
	RCP8.5	-22	-8	7	-13	-6	16

Table 3: GCM projected changes in extreme precipitation for Grenada between the future and historical periods. Time periods from 2036 to 2065 (centred at 2050) and 2071-2000 have been taken as future and historical periods respectively.

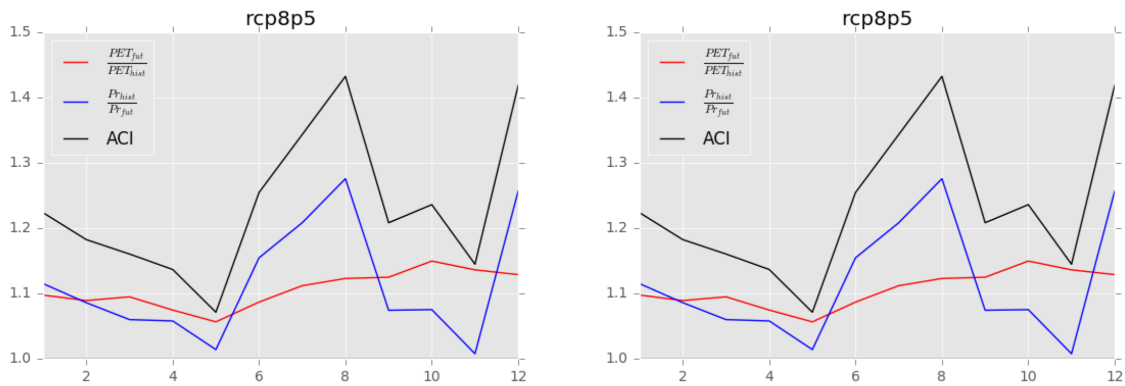

Figure 3: Annual cycle of changes in ACI for 2050, including the contributions of changes in PET and changes in Pr, as compared to historical period. Left and Right panels represent the results for RCP 4.5 and RCP 8.5, respectively

Annual Cycle of Aridity Change Index (ACI) is presented in Figure 3. From Karnauskas (2016) definition, greater than 1 values of PET_F/PET_H, Pr_H/Pr_F and ACI represent increase in evapotranspiration, decrease in precipitation and increase in aridity respectively. From Figure 3, greater than 1 values for all the three curves can be seen for both RCP4.5 and RCP8.5 for almost throughout the year based on the median values of the ensemble. This behavior points towards robust tendency towards increasing aridity over Grenada by mid-century consistently throughout the year. Once again a marked decrease in the water availability can be witnessed pointing towards alarming situation for Grenada in the future.

Discussion

In earlier studies, which are mainly based on AR4 (CMIP3) GCMs and SRES scenarios, a future increase and decrease is reported for temperature and precipitation respectively (e.g. Simpson et al. 2012). Moreover, temperature extremes are also projected to become more severe with precipitation extreme showing mixed behavior. The results presented in the current study, in which improved AR5 (CMIP5) GCMs along with more recent RCP scenarios have been employed, have also brought us almost to the similar conclusion. Hence it adds to the robustness of the earlier conclusions and therefore with more confidence we can say that Grenada is most likely to face water stressed condition in future due to climate change. Additionally, the Aridity Change index and future freshwater availability presented in this analysis also present a gloomy picture for Grenada. The increased aridity throughout the year points towards considerable impacts on freshwater availability especially at the end of the dry season, which generally is the most water-stressed time of the year. Furthermore, a marked decrease in aridity, governed by precipitation decrease, at the start of the wet season amplifies the vulnerability of freshwater availability at the end of the dry season. Additionally, a recent study has suggested an increase of sea level rise of around 1 meter by the end of 21st in the region Caribbean region including Grenada based on RCP 8.5 scenario (Stephenson and Jones, 2017). Since sea level rise can cause flooding, coastal erosion and the loss of coastal regions, therefore it is also most likely to put additional pressure on the over-all freshwater resources of Grenada.

Grenada is also susceptible to tropical storms and hurricanes. According to NASAP 2015, recent historical trend suggests an increase in the number of hurricanes making landfall in Grenada. This study further mentioned a sharp increase in the number of strong hurricanes over Grenada starting in 2002, along with a very little increase or even decrease in the lesser categories storms. These trends are consistent with the global trends, which also show large increase in number and proportion of strong hurricanes even as total number of cyclones and cyclone days decreased slightly in most basins (Stephenson and Jones, 2017). Moreover, since Grenada comes under the influence of tropical storms originating from North Atlantic, the IPCC (IPCC AR5 WG1) found strong evidence for an increase in the frequency and intensity of hurricanes since 1970s in the North Atlantic. Concerning future projections, the IPCC further reads “while projections indicate that it is likely that the global frequency of tropical cyclones will either decrease or remain essentially unchanged, concurrent with a likely increase in both global mean tropical cyclone maximum wind speed and rainfall rates, there is lower confidence in region-specific projections of frequency and intensity”. Based on the historical trends as well as IPCC’s statement on the future projections, it can be inferred that Grenada is likely to see more intense hurricanes in future accompanied by very heavy rainfall events.

On the basis of this analysis, it can be concluded that Grenada is most likely to face water stressed situation in future due to climate change superimposed by the destruction due to hurricanes. This future water stress has important implications for climate change adaptation for vulnerable populations living in Grenada.

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