Incorporating drought risk modelling as a planning tool for climate change adaptation measures in Saint Kitts and Nevis

Drought assessment

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1 Background

1.1 Project summary

In an effort to address the impacts of climate change and climate variability in a sustainable way, access to critical information within the water sector is vital. Drought prediction models can identify areas most susceptible to water supply variability and shortages, and therefore facilitate early action to manage risks. In doing so, this will increase resilience in the water sector to improve use of water resources and therefore ensure food security and water usage including from the agricultural, domestic and tourism sectors in the two islands of Saint Kitts and Nevis.

The overall objective is to incorporate drought risks modelling as a planning tool for climate change adaptation measures in Saint Kitts and Nevis. The main outputs include:

- Map stakeholders and establish a stakeholder working group;
- Assess drought risk and water resources in Saint Kitts and in Nevis;
- Benchmark, design and implement a drought prediction tool in Saint Kitts and in Nevis;
- Train administrators and users of Saint Kitts and Nevis to use the drought prediction tool.

The Project outcomes respond directly to SDG 13 'Taking early action to combat climate change and its impacts' by providing a system that will support planning and decision-making for the sustainable management and conservation of water resources in Saint Kitts and Nevis. The Project will also contribute to SDG 1 (End poverty), SDG 2 (Food security) and SDG 6 (Availability and sustainable management of water) as the drought prediction tool will improve agricultural practices and use of water resources, improve food security and increase the income of rural communities.

1.2 About this report

This report presents a drought assessment for Saint Kitts and Nevis. It provides an overview of historical drought occurrence and discusses the causes and consequences of these. Different types of droughts are discussed together with the impacts these have on a range of economic and social sectors. Key indices for meteorological, hydrological and agricultural drought are analysed and mapped for Saint Kitts and Nevis. Drought vulnerability and risk are discussed in relation to vulnerable sectors and groups, including gender considerations, and the adaptive capacity to manage drought. The thinking and analysis underpinning this report have highlighted a number of considerations to be taken into account during the scoping and design of the drought prediction tool (under Output 3) and these are discussed in the final section.

2 Overview of drought in Saint Kitts and Nevis

2.1 Historical drought occurrence

Caribbean drought is mostly influenced by the El Niño Southern Oscillation (ENSO). The current drought impact potential in the Eastern Caribbean is considered moderate in the dry season and slight to moderate in the wet season. Reporting by the Organization of Eastern Caribbean States (OECS) suggests that in the Eastern Caribbean there has been no robust change in the frequency of short-term drought but there has been an increase in long-term drought during the last twenty years (OECS, 2020).

The Caribbean Region has experienced several (meteorological) droughts since 1990: in 1994–1995, 1997–1998, 2002–2003, 2004–2005, 2009-2010, 2015-2016 and most recently 2019-2020 (Figure 2.1). These events are correlated with the ENSO and result in below-average rainfall and above-average temperatures (Yan, 2018). The 2015-2016 Caribbean multiyear drought was the most severe and extensive period of dry conditions in the Caribbean/Central American Region since at least 1950 (Trotman et al. 2021).

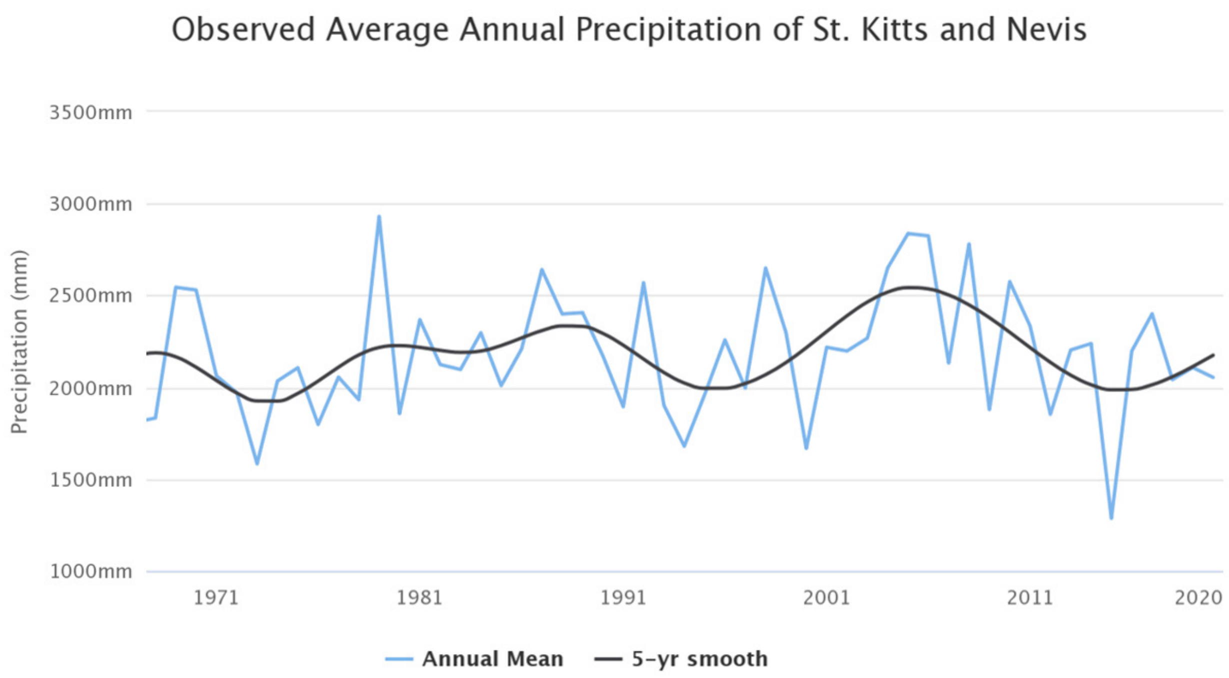

Figure 2.1: Average annual precipitation of Saint Kitts and Nevis

Source: Source: modified from https://climateknowledgeportal.worldbank.org/

The impacts of the droughts of 2009-2010 and 2015-2016 throughout the Caribbean have been well documented by Farrell et al. (2010), CIMH & FAO (2016) and Trotman et al. (2020). These impacts can be broadly summarized as:

- Significant decline in rainfall (2015 - driest on record in 7 Caribbean territories);
- Impacts on agriculture (2015 - reduced agricultural production in 13 countries);
- Significant increase in food prices;
- Increase in bush fires;
- Decreased water storage and flows (2015 - water shortages in 8 countries).

St. Kitts and Nevis, with less than 1,000 m^3 freshwater resources per capita, is one of the most water-scarce countries globally (CIMH & FAO, 2016; Trotman et al., 2017). Given that climate change is already exacerbating drought conditions, water availability is becoming an even more limited resource. In fact, St. Kitts and Nevis felt the severe impacts of regional drought in both the 2009–2010 and the 2015-2016 droughts. The drought of 2015-2016, one of the most widespread in the region, had long lasting impacts especially related to decrease in water storage and flows across both islands. It resulted in severe water deficits across both islands and was compounded by an overall increase in water demand from various sectors over the five years between both droughts.

2.2 Impacts of recent droughts

Some of the impacts of these recent droughts can be summarised as:

Significant decline in rainfall

- Rainfall at RLB International Airport in Saint Kitts and VWA Airport in Nevis in 2015 was the lowest in over 40 years of recording, with only about 25 inches of rainfall.
- Decreased rainfall (below 37 inches compared to a long-term annual average of 46 inches) in 1990-1991, 1993, 1997 and 2000 were highlighted by Jackson (2001) in a history of drought in Nevis.

Decreased water production and salinity

- During the drought of 2009-2010, for St. Kitts the impacts of the drought were most felt in source water production with the water produced from surface water intakes in February 2010 decreasing on average by 15% compared to the same period in 2009. Excess capacity produced by a network of 30 groundwater wells together with conservation actions made up for the shortfall.
- During the 2015-16 drought, water produced from surface water springs decreased by 50% in some cases and levels of salinity increased for several wells in the vulnerable Basseterre Valley Aquifer.

Decreased water storage

- Under normal conditions, storage tanks operate at or above 80% of full capacity whereas during the height of the 2009-10 drought (week of February 7th, 2010), levels at two of the largest storage tanks were down to 53% (Morne Peak) and 33% (La Guerite) of full capacity (SKWSD, 2010).

Water rationing and demand management

- As a result of the 2015-16 drought, daily water rationing (complete shut off of supply) from 10pm to 5am started in mid-2015 and remained in place into 2017. This was the first time in the history of the utility in Saint Kitts that water rationing had to be enacted.
- Other water demand control measures implemented by the Saint Kitts Water Services Department (WSD) included restrictions on car washing, irrigation of grass and other non-essential tasks along with strict monitoring of public standpipes.
- Similar impacts were felt in Nevis and water rationing was also instituted by the Nevis Water Department (NWD). In fact, steps have been taken to promote rainwater harvesting and emergency water storage on Nevis as result of recent droughts[1].

Other sectoral impacts

- The Federation recorded a reduction in crop production by approximately 31% in St. Kitts and 36% in Nevis because of the drought of 2015-2016 with very little recovery in the years since.
- This has had wide ranging impacts on the livelihoods of farmers, national food security and associated increase in food importation from 20% of total imports in 2014 to 25% of total imports in 2017.
- The severe decrease in water production also forced the Saint Kitts WSD to stop providing water to cruise ships and other sectors as it sought to focus on the domestic sector (SKWSD, 2018).

The country has employed various measures to *respond* to drought and water scarcity overall, such as encouraging the reduction in water demand/usage; and augmenting water supplies where possible, see also Section 5. However, there needs to be a linkage between the science and information provided to policy makers and major water users in order to enhance *pro-active* efforts to manage water resources, particularly as climate projections indicate more substantial increases for drought during the dry season, especially considering long-term trends.

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[1] On October 26, 2021, the Nevis Island Administration signed the Ordinance - Nevis Physical Planning and Development Control Regulations, 2021. These new regulations have now made it mandatory for any “building which is intended for human habitation shall be provided with a cistern or rainwater catchment and a storage facility”. Prior to this ordinance, there was no mandate to enforce rainwater harvesting in buildings around the island (T. Bartlette, Manager NWD, pers. communication 2021).

3 Understanding drought

3.1 Types of drought

Among the weather-related natural disasters, drought is likely to be the most complex and severe due to its intrinsic nature and wide-ranging and cascading impacts that affect, among others, water resources and supply, agricultural production, tourism, human health, biodiversity and natural ecosystems. Understanding the drought phenomenon and adopting a pro-active drought risk management ethos is critical to manage and mitigate negative impacts.

Droughts are monitored and quantified by sector-oriented drought indicators, typically derived from hydro-climatic variables like precipitation, climatic water balance, soil moisture, river flow, and groundwater. In addition, related impacts, such as reductions in greenness or vegetation vigour are often used indicators.

Most commonly, drought indicators are presented in the form of standardised indices used to analyse droughts in different domains of the water cycle. Drought indicators are usually designed either for drought monitoring and awareness raising or for water management (Beguería et al., 2014). However, they are also useful for drought forecasting (Dutra et al., 2014; Sheffield et al., 2014), climate change studies (Trenberth et al., 2014; Dai et al., 2018), and as input for drought impact modelling (Zampieri et al., 2017) and drought risk assessments (Svoboda et al., 2015).

Droughts can last from a few weeks to several years and the related impacts can develop slowly and often linger even after the end of the drought itself. Depending on the effect in the hydrological cycle and the impacts on society and environment, different drought types are commonly distinguished, see Box 3.1.

Box 3.1: Types of drought

1. *Meteorological drought* is a period of months to years with a deficit in precipitation or climatological water balance (i.e. precipitation minus potential evapotranspiration) over a given region. The deficit is defined with respect to the long-term climatology. A meteorological drought is often accompanied by above-normal temperatures and precedes and causes other types of droughts.
2. *Hydrological drought* occurs when river stream flow and water storages in aquifers, lakes, or reservoirs fall below long-term mean levels. Hydrological droughts develop more slowly because they involve stored water that is depleted but not replenished. Time-series of these variables are used to analyse the occurrence, duration and severity of hydrological droughts.
3. *Agricultural (or soil moisture) drought* is a period with reduced soil moisture that results from below-average precipitation, less frequent rain events, or above-normal evaporation.

3.2 Drought risk

Drought risk is the likelihood to incur damages and economic losses during and after a drought and depends on the interactions between three dimensions:

1. The severity and the probability of occurrence of a certain drought event;
2. The exposed assets and/or people; and,
3. Their intrinsic vulnerability or capacity to cope with the hazard.

The large variety of drought impacts point to a multitude of drivers that turn lower than average precipitation, limited soil moisture and low water levels into disasters for vulnerable communities and economies (UNISDR, 2011). Therefore, drought risk not only depends on the characteristics of the physical hazard (intensity, duration, severity), but also on the exposed assets (e.g., crops, people, water intensive industries, natural ecosystems) and the vulnerability of the affected society and ecosystems.

Following this definition, the risk to incur damages and economic losses from a drought depends on the combination of the severity and the probability of occurrence of a certain event, the exposed assets and/or people, and their intrinsic vulnerability or capacity to cope with the hazard. Table 3.1 summarises the main characteristics of the three components of drought risk as well as relevant data needed to represent them.

Table 3.1: Components of drought risk analysis (Vogt et al., 2018)

Component	Characterization	Data
Hazard	Magnitude of a hydro-meteorological deficit	Meteorological, hydrological and/or biophysical indicators
Exposure	Amount of elements and assets subject to a drought hazard	Quantity and location of human population, infrastructure, economic activities and/or ecosystems
Vulnerability	Sensitivity of exposed elements to damaging effects of droughts	Composite indicators that include social, economic, environmental and/or infrastructural components
Overall risk	Potential damages and losses from droughts to a specific asset	Measured in a probabilistic scale as a combination of the drought magnitude or severity, level of exposure and vulnerability. Linked to intervention policies and management plans

3.3 Drought characterisation

To obtain an overview of the potential impacts of droughts, a set of variables is needed in order to represent different aspects related to the water deficit. Among the key drought variables are frequency, severity (or magnitude), intensity and duration. These key variables are described in Table 3.2.

Severity describes the accumulated deficit over the entire duration of an event, while intensity describes the average degree of the precipitation, soil moisture, or water storage deficit during a drought. Both may include consideration of the associated impacts.

The duration and area affected are linked to the propagation in time and space of the water deficit. Longer and more widespread events might thus trigger cascading effects, the magnitude of which is directly related to the water deficit. The timing of the onset, cessation and end of a drought are particularly relevant information during the crop growing season.

Table 3.2: Main variables used to characterise drought events (Vogt et al., 2018)

Variable	Description	Relevance
Frequency	Number of drought events per defined time interval.	More frequent droughts can cause long-term impacts on affected ecosystem.
Severity (Magnitude)	Related to the water deficit. Computed as the sum of the differences, in absolute values, between the drought indicator (DI) values and the threshold used to define the level of dryness. $S_{ii}=\Sigma \lvert DI_{ii} \rvert <$ Threshold.	Deficit of water in relation to the water needed for specific uses (e.g. irrigation, domestic water consumption, energy production, etc.)
Intensity	Severity divided by duration of the event.	Characterizes the overall potential for impacts.
Duration	Number of days, months or time steps of the event.	Longer droughts propagate further through the hydrological cycle with a higher potential for cascading and secondary effects.

Variable	Description	Relevance
Onset	First day, month or time step for which the indicator is below a given threshold.	Relevant if a drought starts in sensitive periods with greater water demand like seeding and flowering periods. Relevant for drought management and the declaration of farming emergencies.
Cessation	Meteorological indices have returned to normal, soil moisture is restoring, pasture growth re-establishes, forest growth re-establishes, reservoirs and lakes refill.	Relevant for management.
End-point	Agricultural and natural ecosystem productivity returns to average pre-drought conditions, Lake and reservoir levels return to average pre-drought conditions. Socio-economic conditions return or stabilize to normal conditions.	Relevant for management.
Peak month	Day or month with the lowest value of the drought indicator.	Period with the potentially strongest impact.
Area affected	Area or percentage of a region (or country) with values of the drought indicator below a certain threshold.	The wider the area, the more exposed assets are affected.

3.4 Potential drought impacts

Drought has strong linkages to water scarcity and food security alongside broader national interests related to wider social and economic development and poverty. Chapter 3 *Vulnerability and Adaptation Assessment for St. Kitts and Nevis* of the 3rd National Communication to the UNFCCC (Burrowes et al., 2021) acknowledges the importance of drought in Saint Kitts and Nevis and summarises the potential impacts of drought across a range of sectors as a result of both seasonal variability and the on-set of longer-term changes due to climate change, see Table 3.3.

Table 3.3: Typical sectoral impacts of drought

Sector	Potential impacts
Water resources (including watersheds and water supply infrastructure)	■ Reduced aquifer recharge and reducing sustained yields from ground water sources ■ Possible over-pumping in coastal aquifers leading to salinization ■ Water deficits for all users – compounded by increasing evapotranspiration losses ■ Possible increased reliance on desalination, imported or bottled water sources ■ Indirect waste management issues related to bottled water packaging ■ Water Stress to vegetation and increase in fire risk ■ Increased watershed degradation and changes in vegetation succession to less humid-adapted plants ■ Desertification of marginal lands in extreme cases – with increased dustiness ■ Reduced infiltration capacity related to denuded soils ■ Increasing hillside denudation can lead to increases in wind speeds, which can exacerbate dustiness and wildfire risk ■ Loss of forest cover and decline in infiltration rates, which impact aquifer recharge potential and water supply.
Agriculture	■ Higher losses in farms unable to transition away from rainfed agriculture – farmers rely on rains between September and October ■ Increasing demand for irrigation and soil moisture retention technologies ■ Declining profitability of producing high-water demand crops ■ Declines in crop yields and quality of pasture for livestock ■ Decline in soil fertility with lower organic and moisture content, increasing friability and erosivity ■ Declining quality of pasturelands and increased demand for feedstock or greater acreage to support herds ■ Increased competition with non-agricultural consumers for water supply ■ Shortages of traditional foods and national Staples ■ Increased reliance on imported, frozen and processed foods. ■ Possible impacts on crop diversity, which can affect the economics of farming and resilience to shocks ■ Increased need for government relief for farmers to maintain domestic food production systems ■ Increased susceptibility to diseases and pets – resulting in higher costs ■ Possible impacts on pollinators ■ High vulnerability and risk of economic losses of rainfed systems (90% of all farms in St Kitts and Nevis) ■ Increased costs associated with irrigation and soil moisture retention. Indirect impacts on the cost of mulch grass species ■ Possible declining productivity and yields of crops that require higher moisture ■ Nevis is particularly vulnerable to low and unreliable rainfall and extended periods of drought – limiting food security on that island and increasing reliance on imported food.

Sector	Potential impacts
Human health	▪ Heavy use of pesticides in vector control activities may impact human health ▪ Increased need to disinfect and protect domestic water supplies (boil water etc.) ▪ Increased dustiness and smoke (from wildfires) impact respiratory health ▪ Dehydration and illness ▪ Declines in hygiene and sanitation due to water shortages, lock-offs and low pressures ▪ Increased water storage domestically (black tanks and barrels) which may lead to increased waterborne illnesses and vectors ▪ Declines in sanitation and hygiene -impacting overall health ▪ Mental health issues related to trauma of extreme events and loss of social cohesion.
Built environment	▪ Water shortages and rationing ▪ Costs associated with maintenance of silted up water and wastewater systems due to low flows.
Tourism	▪ Visual aesthetics decline with lower levels of landscaping, dustiness etc. ▪ Lower tourism product and experience due to water lock offs, low pressure etc. ▪ An increase in dry days is better for tourists' participation in outdoor activities and benefits the tourism value chain outside of the hotel.

4 Drought indices and mapping

4.1 Drought indices

In this section, a range of drought indices have been analysed to describe different drought conditions for Saint Kitts and Nevis from variables such as precipitation, temperature, runoff, groundwater levels, and soil moisture. Three main categories of drought and their associated indices were considered:

- Meteorological drought:
  - Standardised Precipitation Index (SPI)
  - Standardized Precipitation Evapotranspiration Index (SPEI).
- Hydrological drought:
  - Standardized Water-Level Index (SWI).
- Agricultural drought:
  - Normalized difference vegetation index (NDVI)
  - Normalized Difference Moisture Index (NDMI).

It is recognised that other variables or indices will be of interest to different sectoral users of a drought prediction system. It is anticipated that a focus on 'how much water will there be (e.g. in the next 1, 3 or 6 months may be more practical and pragmatic parameters to support adaptation planning rather than 'how much has it rained recently' or 'what is the groundwater level'. Whilst these cannot be considered at the moment, the development of an integrated groundwater/surface model as part of Output 3 will allow a much greater range of hydrological indices to be considered and calculated as the work moves forward.

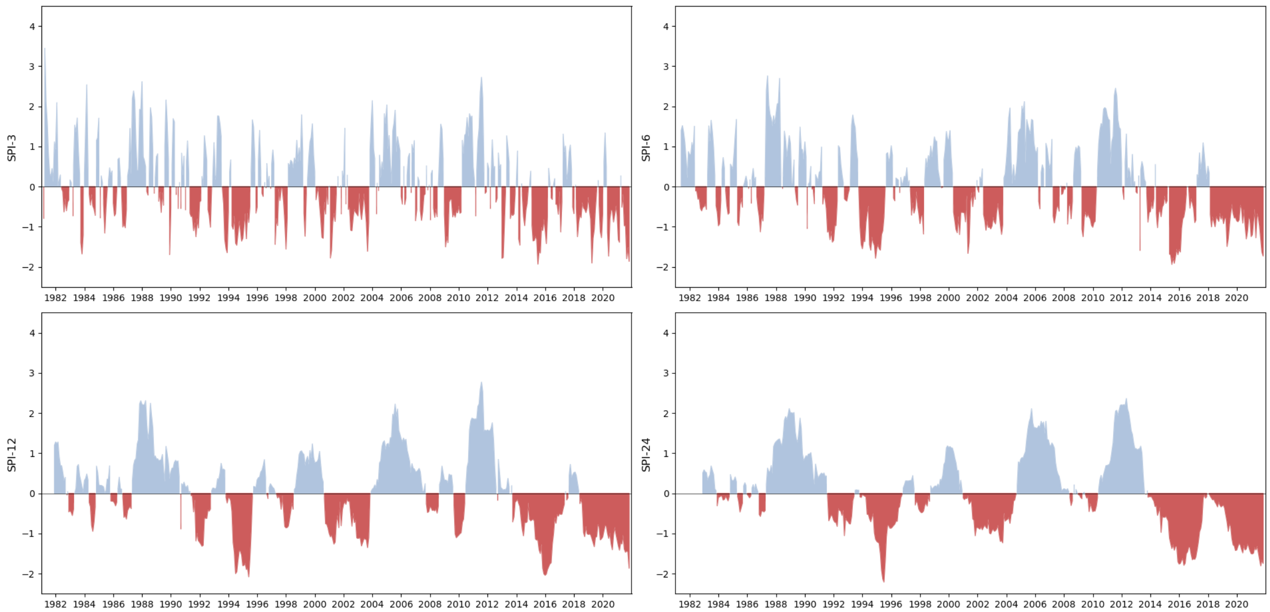
4.2 Meteorological indices

4.2.1 Standardised Precipitation Index (SPI)

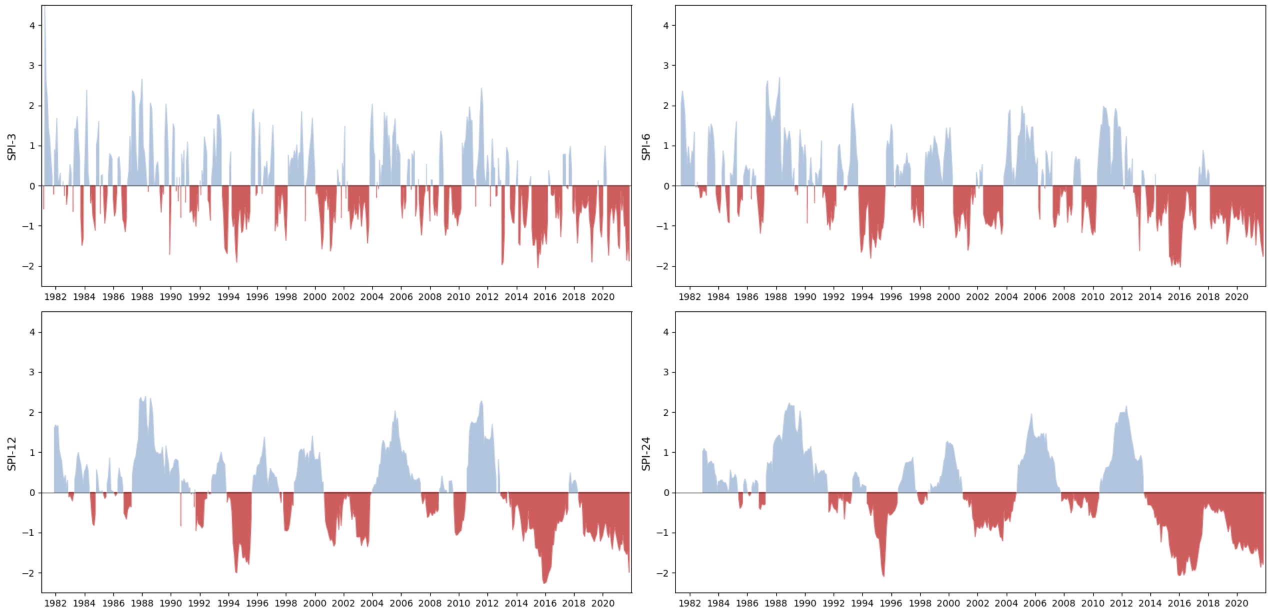
The Standardized Precipitation Index (SPI) is widely used to characterize meteorological droughts on different timescales (MacKee et al. 1993). It was developed by the Colorado State University in 1992 and recommended by the World Meteorological Organization (WMO) as the main meteorological drought index that countries should use to monitor and follow drought conditions (Hayes, 2011). The SPI can be created for differing periods of 1-to-36 months, using monthly input data. Shorter timescales (e.g. 3 months) correlate the results with soil moisture, and longer timescales, show better correlation to groundwater and reservoir storage (Keyantash et al. 2002). SPI has an intensity scale in which both positive and negative values are calculated, correlating to wet and dry events. SPI continuously negative values indicate a drought period and according to McKee et al. (1993) drought begins at an SPI of -1 or less, however other thresholds can be used depending on climate characteristics of the area as more research is done.

Precipitation datasets are used as input parameters. Depending on the SPI timescales, the index can be used for different applications: short timescales can provide basic drought monitoring, or agricultural impact monitoring (6-month SPI or less) while hydrological impacts are investigated with longer timescales (12-month SPI or more). This is because hydrological droughts are usually out of phase with or lag the occurrence of meteorological and agricultural droughts: It takes longer for precipitation deficits to show up in components of the hydrological system (e.g. soil moisture, streamflow, groundwater and reservoir levels).

SPI calculations for 3, 6, 12 and 24 months timescales were made as a mean of gridded datasets for Saint Kitts and Nevis separately (Figure 4.1) using the CHIRPS[2] rainfall dataset, which uses estimates from rain gauge and satellite observations (Funk et al 2015). As shown in the figures below, increases in drought length and intensity are observed in both islands, clearly highlighting the 2015 drought. A spatial approach was also carried out to assess the differences throughout the islands, and examples for 12 and 24 months timescales are shown in Figure 4.2.



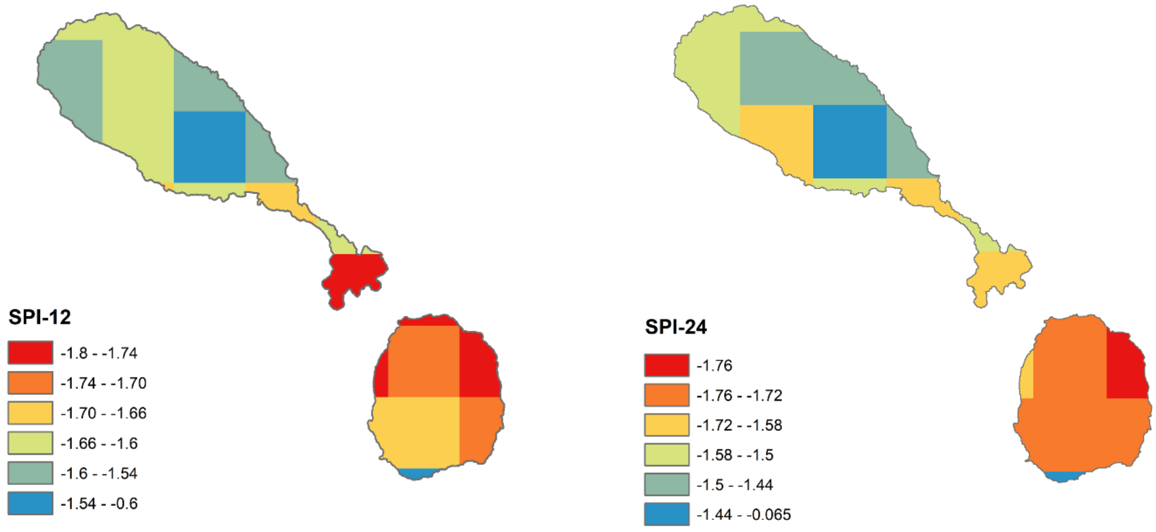
(a)



(b)

Figure 4.1: SPI calculations for 3, 6, 12 and 24 months for (a) Saint Kitts and (b) Nevis

[2] Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) is a 35+ year quasi-global rainfall data set.



(a) (b)

Figure 4.2: Spatial distribution of SPI calculations for 12 and 24 months for Saint Kitts and Nevis

Applications: The ability of SPI to be calculated at various timescales allows for multiple applications. Depending on the drought impact in question, SPI values for 3 months or less might be useful for basic drought monitoring, values for 6 months or less for monitoring agricultural impacts and values for 12 months or longer for hydrological impacts. SPI can also be calculated on gridded precipitation datasets, which allows for a wider scope of users than those just working with station-based data.

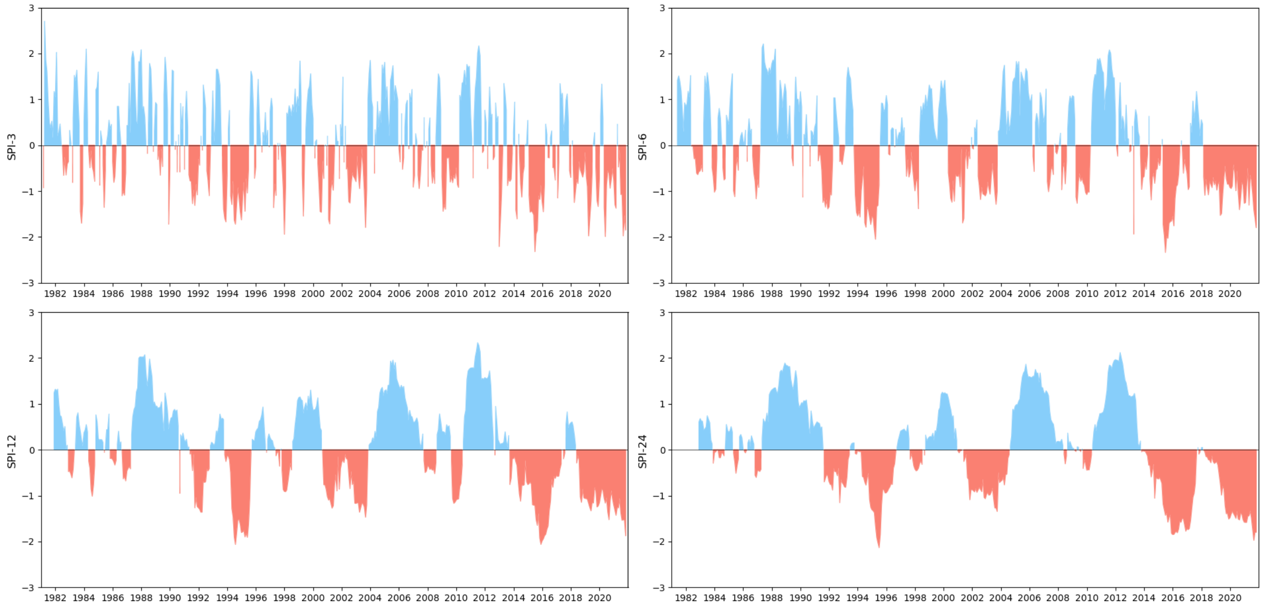
Strengths: Using precipitation data only is the greatest strength of SPI, as it makes it very easy to use and calculate. SPI is applicable in all climate regimes, and SPI values for very different climates can be compared. The ability of SPI to be computed for short periods of record that contain missing data is also valuable for those regions that may be data poor or lacking long-term, cohesive datasets. The program used to calculate SPI is easy to use and readily available. The ability to be calculated over multiple timescales also allows SPI to have a wide breadth of application. Many articles relating to SPI are available in the science literature, giving novice users a multitude of resources to rely on for assistance.

Weaknesses: With precipitation as the only input, SPI is deficient when accounting for the temperature component, which is important to the overall water balance and water use of a region. This drawback can make it more difficult to compare events of similar SPI values but different temperature scenarios. The flexibility of SPI to be calculated for short periods of record, or on data that contain many missing values, can also lead to misuse of the output, as the program will provide output for whatever input is provided. SPI assumes a prior distribution, which may not be appropriate in all environments, particularly when examining short-duration events or entry into, or exit out of, drought.

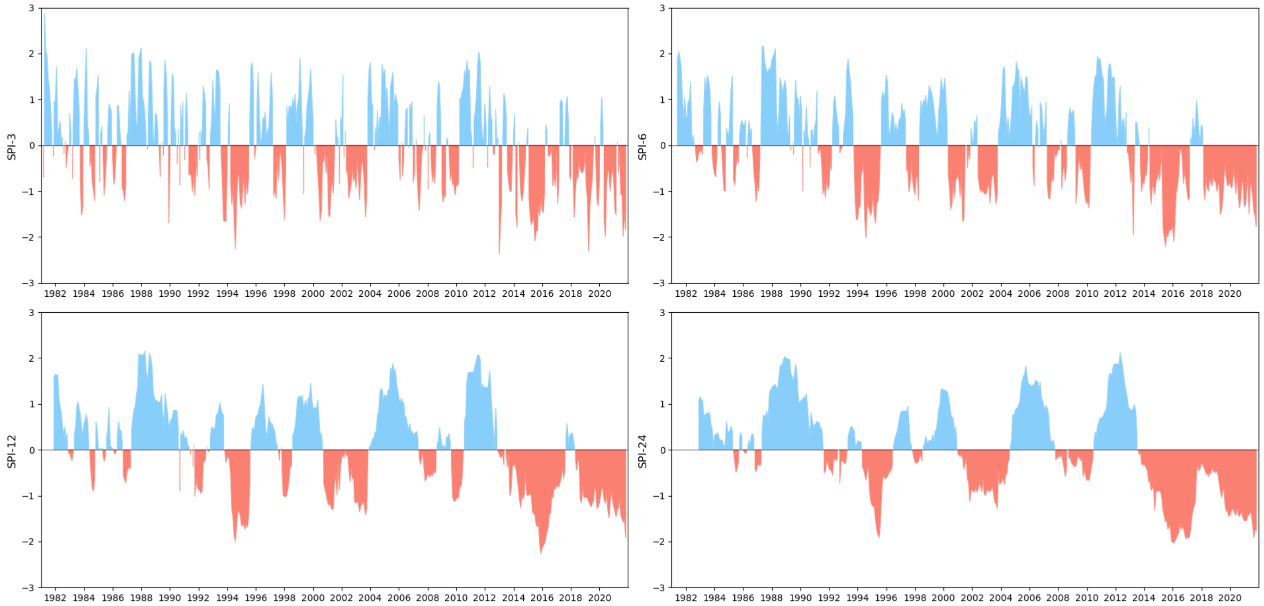
4.2.2 Standardized Precipitation Evapotranspiration Index (SPEI)

Developed by Vicente-Serrano et al. (2010), SPEI provides results taking into account potential evapotranspiration (PET) and precipitation building from the SPI calculation. This is done with a basic water balance calculation, and temperature can be used if PET data is not available as PET can be estimated using the simple Thornthwaite method. As defined for SPI, SPEI has an intensity scale with both positive and negative values which identify wet and dry events. Monthly precipitation and temperature data are used for both small and longer timescales and it can be used to identify and monitor drought impacts.

Following the same reasoning as per SPI, four different timescales (3, 6, 12, 24 months) were used to calculate SPEI for both Saint Kitts and Nevis, averaging the gridded data available for both islands. Results (Figure 4.3) follow the same patterns as shown in the SPI results.



(a)



(b)

Figure 4.3: SPEI calculations for 3, 6, 12 and 24 months for (a) Saint Kitts and (b) Nevis

Applications: With the same versatility as that of SPI, SPEI can be used to identify and monitor conditions associated with a variety of drought impacts.

Strengths: The inclusion of temperature along with precipitation data allows SPEI to account for the impact of temperature on a drought situation. The output is applicable for all climate regimes, with the results being comparable because they are standardized. With the use of temperature data, SPEI is an ideal index when looking at the impact of climate change in model output under various future scenarios.

Weaknesses: The requirement for a serially complete dataset for both temperature and precipitation may limit its use due to insufficient data being available. Being a monthly index, rapidly developing drought situations may not be identified quickly.

4.3 Hydrological Indices

Although all droughts originate with a deficiency of precipitation, water management officials are more concerned with how this deficiency affects the hydrologic system. Hydrological droughts are usually out of phase with the occurrence of meteorological and agricultural droughts. As a result, these impacts are out of phase with impacts in other economic sectors. For example, a precipitation deficiency may result in a rapid depletion of soil moisture that is almost immediately discernible to the agriculture sector, but the impact of this deficiency on reservoir levels may not affect recreational uses for many months.

4.3.1 Standardized Water-Level Index (SWI)

This index developed by Bhuiyan (2004), uses well levels to assess groundwater recharge deficits. This informs drought on groundwater recharge. As there are no main rivers in Saint Kitts and Nevis, data provided from different boreholes in both islands can provide an overview of groundwater deficits. Observed data is scarce in Saint Kitts boreholes and therefore an example from Nevis is shown in Figure 4.4. Data was only available continuously from 2012, showing the impact of the 2015 drought on groundwater levels. However, as this is only information from one single borehole, the results are not necessarily an indication of drought impact of the whole island. Outputs from the modelling exercise in the project could be used to recalculate this index both as a timeseries at different boreholes or spatially, considering groundwater levels.

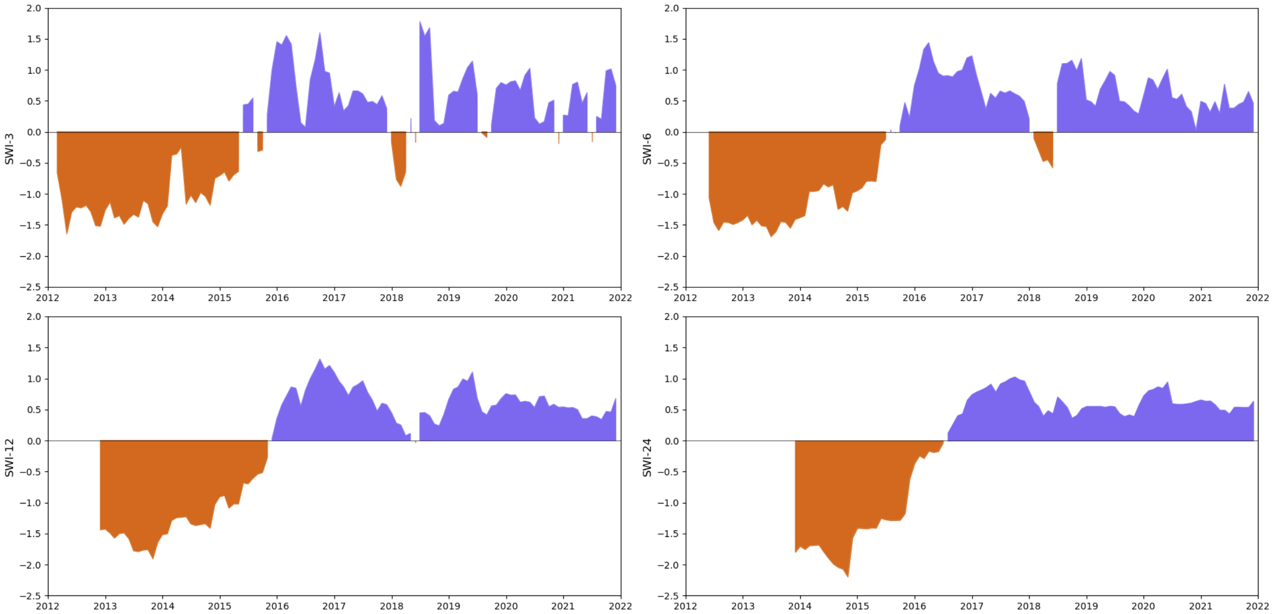


Figure 4.4: Groundwater levels in Madden borehole in Nevis

Applications: For areas with frequent seasonal low flows on main rivers and streams.

Strengths: The impact of drought on groundwater is a key component in agricultural and municipal water supplies.

Weaknesses: Only takes groundwater into account, and interpolation between points may not be representative of the region or climate regime.

4.4 Agricultural indices

Agricultural drought links various characteristics of meteorological (or hydrological) drought to agricultural impacts, focusing on precipitation shortages, differences between actual and potential evapotranspiration, soil water deficits, reduced groundwater or reservoir levels, and so forth. Plant water demand depends on prevailing weather conditions, biological characteristics of the specific plant, its stage of growth, and the physical and biological properties of the soil. A good definition of agricultural drought should be able to account for the variable susceptibility of crops during different stages of crop development, from emergence to maturity. Deficient topsoil moisture at planting may hinder germination, leading to low plant populations per hectare and a reduction of final yield. However, if topsoil moisture is sufficient for early growth requirements, deficiencies in subsoil moisture at this early stage may not affect final yield if subsoil moisture is replenished as the growing season progresses or if rainfall meets plant water needs.

The land cover maps of the islands provide an overview of the characteristics of the terrain (Figure 4.5). Both islands are mountainous with areas of tropical forest in the peaks. Urban areas are located mostly along the coast and patches of crop areas are observed in the north west of Saint Kitts and smaller patches throughout Nevis.

In this section, agricultural indices are calculated for both islands as well as for some of the crop areas classified in the map.

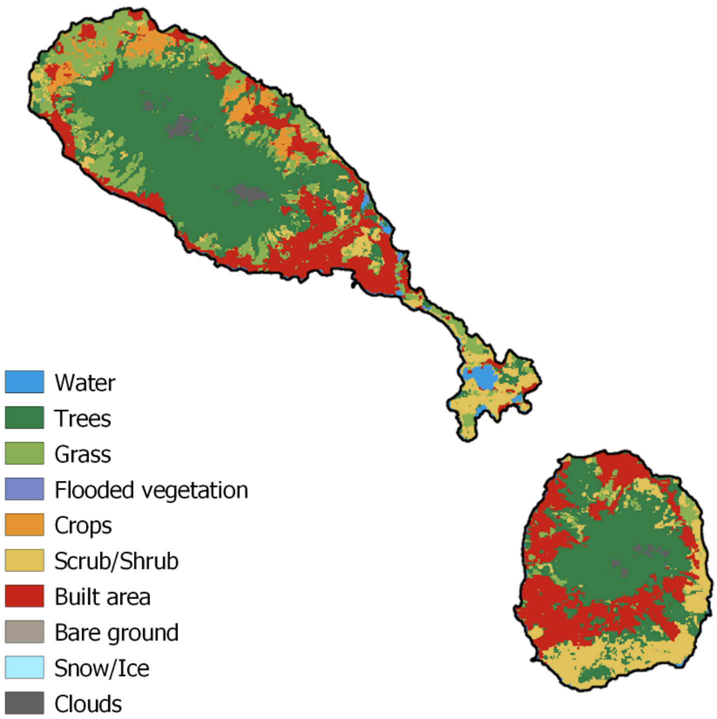


Figure 4.5: Land cover classification for Saint Kitts and Nevis (Karra et al., 2021)

4.4.1 Normalized difference vegetation index (NDVI)

NDVI is an index for quantifying green vegetation. It normalizes green leaf scattering in Near Infra-red wavelengths with chlorophyll absorption in red wavelengths. The value range of the NDVI is -1 to 1. Negative values of NDVI (values approaching -1) correspond to water. Values close to zero (-0.1 to 0.1) generally correspond to areas of rock, sand, or snow. Low, positive values represent shrub and grassland (approximately 0.2 to 0.4), and high values indicate temperate and tropical rainforests (values approaching 1). NDVI, using Sentinel-2 data is defined as:

$$NDVI = (B08 - B04) / (B08 + B04)$$

NDVI for Saint Kitts and Nevis was calculated using Sentinel-2 imagery as shown in Figure 4.6 below.

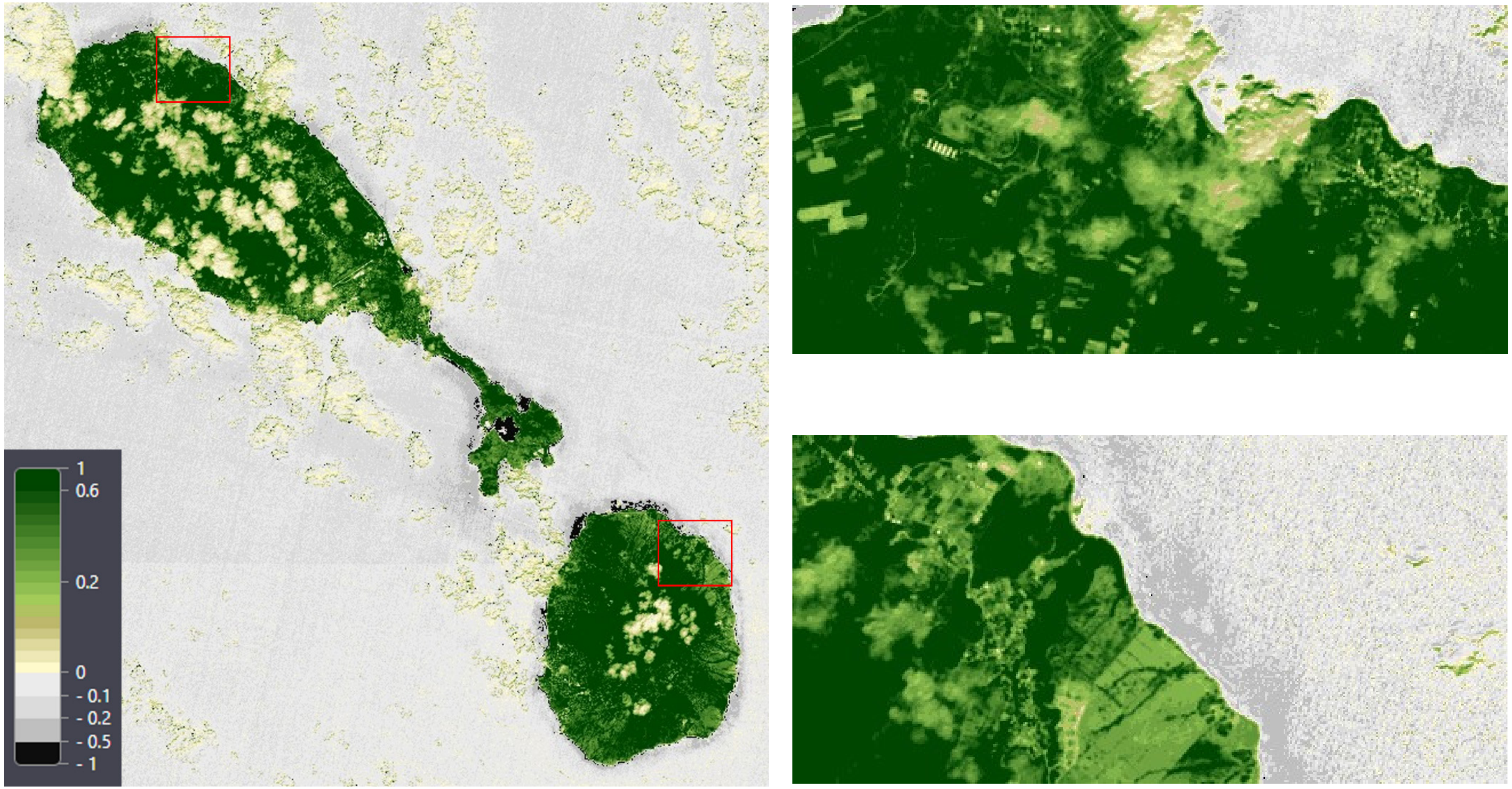


Figure 4.6: NDVI for Saint Kitts and Nevis (left figure) for January 2022. Close up to cropland areas, indicated with a red square, in Saint Kitts (top right) and in Nevis (bottom right) corresponding with less positive values (drier areas)

Applications: Used for identifying and monitoring droughts affecting agriculture.

Strengths: Innovative in the use of satellite data to monitor the health of vegetation in relation to drought episodes. Very high resolution and great spatial coverage.

Weaknesses: Data processing is vital to NDVI, and a robust system is needed for this step. Satellite data do not have a long history.

4.4.2 Normalized Difference Moisture Index (NDMI)

The NDMI is a normalized difference moisture index, that uses near infrared (NIR) and short-wave infrared (SWIR) bands to display moisture. The SWIR band reflects changes in both the vegetation water content and the spongy mesophyll structure in vegetation canopies, while the NIR reflectance is affected by leaf internal structure and leaf dry matter content but not by water content. The combination of the NIR with the SWIR removes variations induced by leaf internal structure and leaf dry matter content, improving the accuracy in retrieving the vegetation water content. The amount of water available in the internal leaf structure largely controls the spectral reflectance in the SWIR interval of the electromagnetic spectrum. SWIR reflectance is therefore negatively related to leaf water content. In short, NDMI is used to monitor changes in water content of leaves, and was proposed by (Gao, 1996). NDMI is computed using the near infrared (NIR) and the short wave infrared (SWIR) reflectances. Calculated using Sentinel-2:

$$NDMI = (B08 - B11) / (B08 + B11)$$

NDMI for Saint Kitts and Nevis was calculated using Sentinel-2 imagery as shown in Figure 4.7. The range of values for the NDMI is -1 to 1. Negative values correspond to barren soil. Values from -0.2 to 0.4 generally correspond to water stress. Highest values, from 0.4 to 1 represent high canopy without water stress. Figure 4.7 shows NDMI values for Saint Kitts and Nevis for January 2022. Based on crop areas observed from land cover maps of Saint Kitts and Nevis, and as it was done for NDVI, close-up figures of both islands are also shown on the right-hand side of Figure 4.7. These close-up figures indicate areas of water stress that might correspond to farmland.

Applications: Used for monitoring of drought affecting agriculture as a method of stress detection.

Strengths: High resolution and good spatial coverage over all terrains. Different to NDVI, as the two indices look at different signals.

Weaknesses: Stress to plant canopies can be caused by impacts other than drought, and it is difficult to discern them using only NDMI. The period of record for satellite data is short, with climatic studies being difficult.

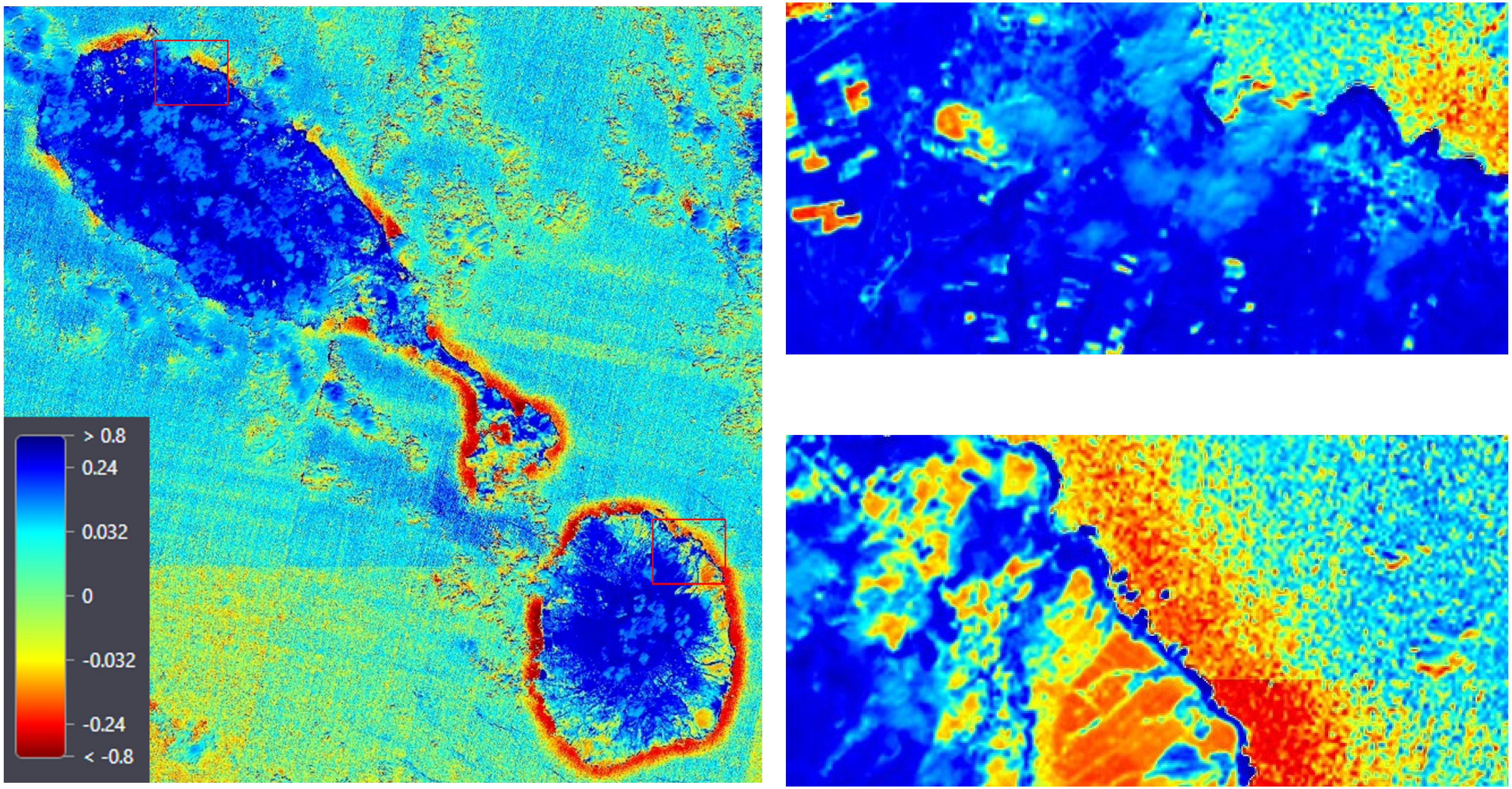


Figure 4.7: NDMI values for Saint Kitts and Nevis for January 2022. Close-up figures of crop areas, indicated with a red square, for both islands are shown on the right-hand side figures. These close-up figures show areas of water stress that might correspond to farmland

4.5 Climate change scenarios

Despite the uncertainty in climate projections, the Caribbean region is likely to experience increased drought frequencies and/or intensities in the 21st century. A reduction in precipitation or changing precipitation patterns as well as greater evaporative demands related with higher temperatures are the underlying processes driving such changes. A temperature increase of 3°C would bring current 100-year droughts (severe droughts that currently only occur once every 100 years) to around 30% of the emerged lands on a 10-yearly basis (Naumann et al., 2018).

Even a global warming target of 1.5°C will still result in significant climatic change in the Caribbean. Agreeing to 1.5°C as a global limit still represents a concession to some degree of change in the climatic regime of the Caribbean and the associated impacts those climatic shifts will bring. In a 1.5°C future, in comparison to the present, the Caribbean will be warmer, with longer warm spells and longer hot and dry spells, and will experience moderate to extreme drought approximately 16% of the time. Particularly, for temperature extremes, the changes seen at 1.5°C also suggest unfamiliar conditions compared to the present with which the Caribbean will have to contend (e.g., up to 120 more warm spell days) (Taylor et al., 2018).

Based on the same method used to calculate SPI for different temporal resolutions with CHIRPS precipitation data, a range of future rainfall projection scenarios from CMIP6 climate models[3] are used to calculate future projections of a 24-month SPI, for both Saint Kitts and Nevis (Figure 4.8).

[3] CMIP6 models: CMCC-CM2-HR4_r1i1p1f1, CNRM-CM6-1-HR_r1i1p1f2, EC-Earth3P-HR_r1i1p1f1, EC-Earth3P-HR_r2i1p1f1, EC-Earth3P-HR_r3i1p1f1, ECMWF-IFS-HR_r1i1p1f1, FGOALS-f3-H_r1i1p1f1, HadGEM3-GC31-HH_r1i1p1f1, HiRAM-SIT-HR_r1i1p1f1, MPI-ESM1-2-HR_r1i1p1f1 (https://pcmdi.llnl.gov/CMIP6/).

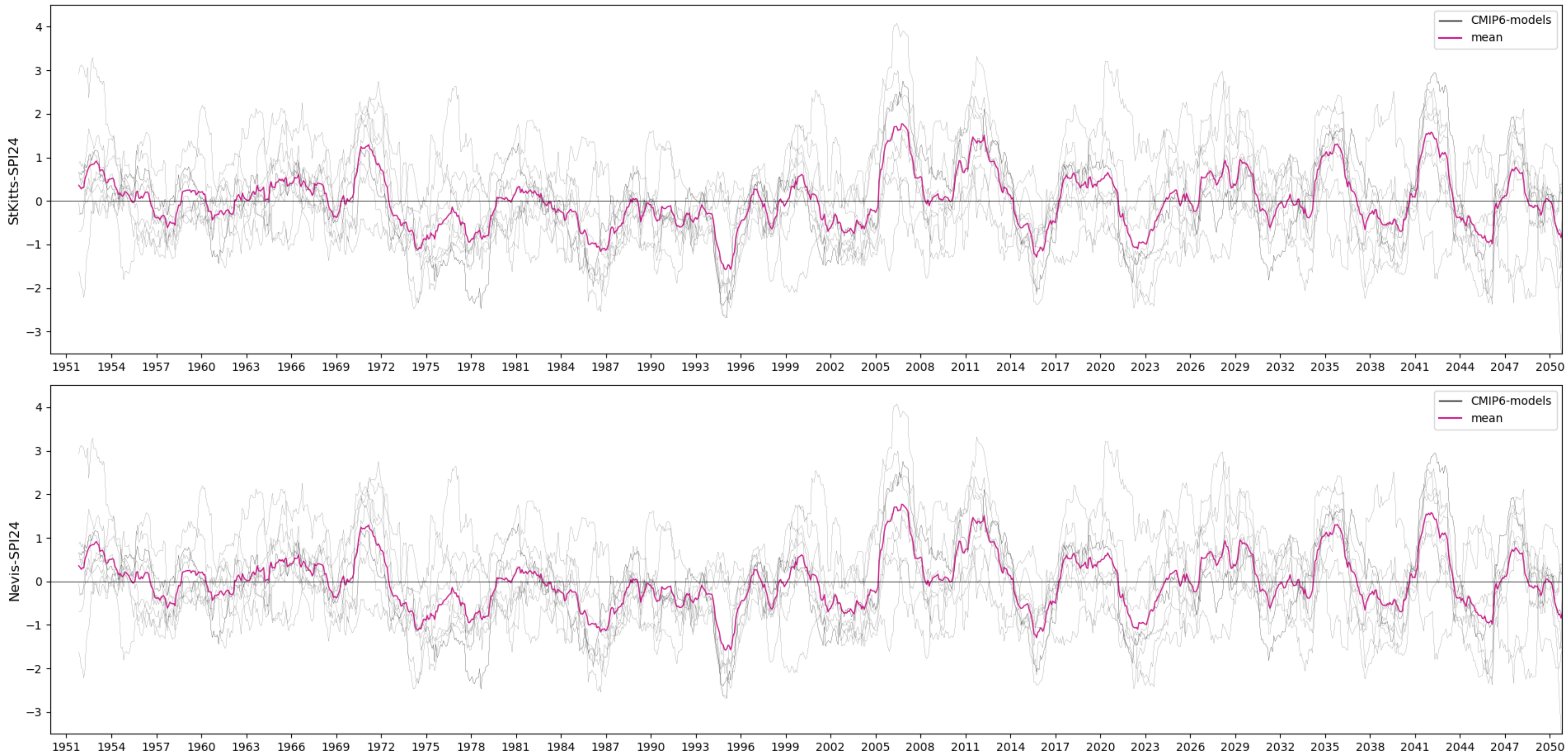


Figure 4.8: SPI-24 calculated for Saint Kitts and Nevis using CMIP6 climate models (individual black lines). The mean SPI-24 of all models is also shown (red line)

5 Drought vulnerability and risk

5.1 Key sectors vulnerable to drought

St. Kitts has approximately 31 surface water systems as delineated watersheds, and one major groundwater basin, which is the Basseterre Valley Aquifer system (although groundwater wells exist in other minor coastal aquifers around the island). The island presently experiences a shortfall between water supply and demand, therefore drought conditions will exacerbate the impacts currently being experienced (i.e. rationing and rota-cuts to supplies), with attendant impacts on users and direct impacts on the economy whereby potable water cannot be made available to some commercial users.

Nevis water sources are almost exclusively groundwater, consisting of both shallow coastal aquifers primarily, and deep aquifers. The deep wells have helped to mitigate the effects of drought over the past decade as they provide more reliable supplies than the coastal wells, which are vulnerable to saline intrusion. A deep well drilling programme in 2008 brought additional supplies on line, helping make Nevis more resilient in drought periods. However, growth and development has now meant that no spare capacity exists in the sources, especially during the dry season when there is peak demand.

Tourism is a mainstay of the economy of St. Kitts and Nevis, and requires a consistent and high quality water supply to service both hotels and cruise ships. In St Kitts, the pressure on water supplies has led to the requirement for major new tourism developments to construct and use their own private desalination systems.

Agricultural diversification has also been an important policy following the closure of the sugar industry almost two decades ago but still requires much support in the face of climate change. Agriculture is generally rain-fed but there is a growing awareness of the needs of famers for access to water for crops during the dry season.

Water is critical in the public health sector and particularly for sanitation, hygiene and ultimately to prevent the spread of infectious diseases. In an era of COVID-19, where there is a notable increase in the use of water for cleaning and sanitisation, St. Kitts and Nevis is at a greater risk from the socioeconomic impacts associated with drought.

5.2 Gender and vulnerable groups

Stakeholders consulted in the preparation of the St Kitts and Nevis Vulnerability and Adaptation Assessment Report (2021) for the country's Third National Communication to the UNFCC, have identified migrants, the elderly, youth, single mothers, women and those in the informal sector as the most vulnerable to climate change impacts generally.

In St. Kitts and Nevis there is a higher concentration of women involved in tourism, housekeeping, reception, food and beverage services, personal care services etc. Tourism has been identified as one of the more climate-sensitive sectors, which has been severely impacted in the past 5 years by hurricanes and the global pandemic. Conversely, men outnumber women in agricultural production (7:3) and are more likely to be involved in low-paying jobs (Government of St Kitts and Nevis, 2021).

The report also states that the elderly are more prone to illness and are generally less physically able to withstand the weather extremes (drought is often accompanied by higher than normal temperatures); or impacts associated with drought. For instance, the elderly are more prone to dehydration which can be life-threatening. Additionally, individuals in this group, particularly if they live alone, may not be as informed about emergency response procedures including drought management in the home.

The poor are more exposed to unhygienic conditions (vector-borne diseases and pests) and have lower adaptive capacity as they may have less access to health care, and possibly have limited access to information.

It is worthy to note that the percentage of women who live in poverty in St. Kitts is a little higher than that of poor men, corresponding to the gender ratio of the population. Women are also more likely to be indigent. However, although men have a slightly higher likelihood of being employed generally, women within the poorest socio-economic quintile have a higher employment rate than men, which is unlike the pattern observed in Nevis and other OECS territories (Simpson et al., 2012).

The Caribbean Water Initiative (CARIWIN) project, (2006-2012) identified that when it comes to the domain of water, there are very segregated roles for women, men, and children (BCWRM & CIMH, 2007). St. Kitts & Nevis did not participate in the pilot initiative; however its findings are relevant to Caribbean SIDS. During times of water scarcity or drought, when water must be accessed from community faucets, water trucks, irrigation ditches, rivers and wells, women's responsibilities in sourcing and allocating water for domestic use tend to be significantly increased.

Small crop farmers have high reliance on the rain and tend to have less access to information about how to make their operations more resilient to drought and other climate extremes. Having limited financial means, they often only have access to appropriate irrigation infrastructure through government programmes or externally funded small-scale projects.

5.3 Adaptive capacity to manage drought

St. Kitts and Nevis has a long history of addressing sustainable development, particularly soil and water conservation. While there is no specific legislation addressing climate change, sustainable development or drought, there are a number of legislative and regulatory instruments that have direct and indirect linkages to drought.

Water management is governed by the 1956 Water Courses and Water Works Act which, by the admission of the water utility, is outdated. The need for a water policy and a revamp of the institutional arrangements was identified as a priority by the Water Services Department (St. Kitts) and the Nevis Water Department as a result of a policy and legislative review carried out in 2010. Under the GEF-IWCAM Project a draft for a new water resources act was developed. Under the OECS RRACC project, a template national water policy was developed and is now being adapted for Saint Kitts and Nevis under IWEco.

Current investments and pipeline projects focus particularly on resilience to climate change but there are also investments that focus on the water sector. Over the last 10 years St. Kitts and Nevis has secured more than USD 20 million of funding for on-going or recently completed water and climate change projects from USAID, GCCA and the GEF. Regional projects include:

- USAID Climate Change Adaptation Program (CCAP) which is being implemented by the CCCCC;
- The Global Climate Change Alliance project on climate change adaptation and sustainable land management in the Eastern Caribbean;
- GEF CReW+ An Integrated Approach to Water and Wastewater Management Using Innovative Solutions and Promoting Financing Mechanisms in the Wider Caribbean Region;
- GEF Integrating Water, Land and Ecosystems Management in Caribbean Small Island Developing States (IWEco);
- GFDRR Revisiting Resilience in the Caribbean;
- GCCA+ Enhancing Climate Resilience in CARIFORUM countries.

In addition to this project - Incorporating Drought Risk Modelling as a Planning Tool for Climate Change Adaptation - current investments and pipeline projects continue to focus on resilience to climate change in the water sector and include, for example:

- Forests and land use in adapting to climate change and increasing the resilience of the livelihoods of peoples and communities and the ecosystems they depend upon in St. Kitts and Nevis (Working draft GCF Concept Note which includes a component on “Water catchment of sustainable livelihoods”);
- Enhancing the water security of smallholder farmers against climate risks in St. Kitts and Nevis (Working draft GCF Concept Note);
- Building Resiliency in the Water Supply Sector in St. Kitts and Nevis (Submitted GCF Concept Note, currently being updated by the Government of the Federation of St. Kitts and Nevis);
- Improving Environmental Management through Sustainable Land Management in St. Kitts and Nevis (Four-year approved project, funded by the GEF through UNEP to commence in 2021) which includes watershed protection and the construction of ponds and dams for selected farmers;
- Safeguarding water security in the Caribbean in a changing climate (Phase I) (submitted GCF Concept Note for 3 countries);
- Vulnerability Assessment and Water Utility Adaptation Plans project and funding for adaptation project investments for rainwater harvesting and emergency water storage, particularly in relation to government facilities and community buildings (funded through the GCCA+);
- The preparation of a Technology Needs Assessment (TNA) funded by the GEF, of which water has been selected as one of the sectors under the adaptation component;
- The Revised and Updated National Determined Contribution also features the challenges experienced within the water sector. Key recommendations are also provided.

Significantly, St. Kitts and Nevis completed an updated *Water Sector Adaptation Plan* in 2021, and as expected, many of the interventions support drought management. The Plan is based on a rapid vulnerability assessment of the water sector, extensive stakeholder engagement and a consideration of policy, legislative and institutional capacity that support climate change adaptation in the water sector. It has six *Priority Programmes* for the water sector but four of them include proposed interventions that directly address drought. The interventions have been made within the context of St. Kitts and Nevis having already made some progress with respect to managing drought, and other climate change impacts:

- *Priority Programme 1: Policy, Legislation and Capacity Development* aims to enhance the national framework of policy, laws and institutions necessary for St Kitts and Nevis to make their water infrastructure, systems and institutions climate-resilient. The national policy framework is to follow the principle of Integrated Water Resource Management, and with climate resilience as a core aim.
- *Priority Programme 3: Climate Resilient Water Services* responds to the threat posed by water scarcity, climate change and increasing consumer demand by recommending investments in exploring new water sources and providing continuity of service in drought conditions which at present are causing supply deficits.
- *Priority Programme 4: Water Demand Management* is complementary to the institutional reforms in Programme 1 and proposes interventions to effectively manage water demand as a key component of achieving water security. It also recommends measures to reduce non-revenue water, which has the added benefit of increased revenue to the water utility. Together, these measures would provide improved levels of service in the face of drought and future climate change.
- *Priority Programme 6: Disaster Risk Management* proposes actions to improve the physical resilience of supply systems and strengthening the institutional systems involved in preparing, managing and recovering from extreme weather events. The risks posed by drought (as opposed to extreme weather) are addressed separately in Programme 3 ‘*Climate resilient water services*’, but included here since

Emergency Response Plans recommended for revision, should include directives for drought, floods, water quality and pollution crises, and other aspects of national disaster risk response.

6 Considerations for the drought prediction tool

Drought forecasting can positively impact agricultural activity and water availability, and is therefore particularly important for ensuring food and water security. Effective forecasting systems can give enough lead time to adequately plan for water storage, identify alternative sources of freshwater, implement new (water-saving) agricultural practices, and import food and water, if necessary.

Detailed specification of the drought prediction tool will be progressed in close consultation with users and administrators under Output 3 as part of the benchmarking, design and implementation of the drought prediction model. However, even at this early stage of the project, a number of factors to take into consideration during the scoping and design of the system are worth highlighting, for example:

- No single drought index can be used to determine appropriate management and mitigation actions for all types of droughts, particularly given the variety of sectors affected by droughts.
- There are various methods that can be used to forecast droughts, including those based on historical correlations between key variables and model simulations. Machine learning methods have also been used recently to forecast droughts, using drought indicators such as the Standardized precipitation Index (SPI) as data input.
- Hydrological indicators (e.g. soil moisture index), real-time meteorological observations, and meteorological forecasts, coupled with historical weather patterns, provide input data to models used to forecast the hydrological conditions in a specific area, and determine whether there is an increasing risk of drought.
- Accessibility of remote sensing and local meteorological data is key for producing the relevant indices. Improving data collection and sharing among institutions is an important part of the process.
- Hydro-meteorological or hydrological indicators, such as the NDVI or SPEI are common indicators used to assess drought risk. These remote-sensing based indicators can then be coupled with data on population and assets in the area, as well as the community's vulnerability to damage by drought, to assess the drought risk.
- A database should receive all data and include essential processing models that produce a warning message when drought risk reaches a predefined threshold value.

Ultimately, it is anticipated that accurate prediction of drought with sufficient lead time will be able to support adaptation planning and decision making by providing valuable information on how much water is likely to be available to help in the management of water sources and supplies. In doing so, it will also help various sectoral interests by:

- supporting water-use directives for the domestic and commercial sectors ahead of time so as to avoid or reduce water rationing and cuts which reduce sanitation and hygiene in the home; and business disruptions, especially in the tourism sector;
- aiding agricultural planning and thereby reduce losses in agricultural production, leading to improvements in food security; and,
- supporting planning in the health sector to mitigate potentially life-threatening impacts from compromised sanitation, hygiene and safety.

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