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Measuring the Severity of Dry Seasons in the Grenadines

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Abstract: *To reduce the negative consequences of extended dry seasons, particularly on islands that have relatively low annual rainfall and depend primarily on rainwater harvesting, there is need for a better understanding of the drought and dry season hazard and the factors that influence the islands' vulnerability to this hazard. This paper analyses dry season rainfall for the Grenadines and proposes a new methodology for measuring the severity of dry seasons and droughts for the islands. The proposed severity index is based on the well-established, standardised precipitation index. The application of the new index to dry seasons over past 80 years shows that the 2009/2010 drought was one of the worst in the history of the Grenadines. The results also show that in the last decade dry seasons are becoming more pronounced.*

Keywords: *Dry season severity index, Grenadines, 2010 Drought*

1. Introduction

The Grenadines, in the Eastern Caribbean, experience two distinct seasons—a dry season that normally begins in January and lasts for as long as 6 months; and a rainy season from June or July to December. As these islands are dependent on rooftop rainwater harvesting (RRWH) for a significant portion of their water supply, periods of low rainfall create high anxiety among islanders. When below average rainfall is experienced during either the dry or rainy seasons, islanders can experience severe water shortages. Until recently, the impacts of dry season have not been systematically recorded as islanders have, over the years, developed good mechanisms to cope with the shortage of drinking water during the dry season. During extreme dry seasons like in 2009/2010, water has to be barged from the main islands of Grenada and St. Vincent, to the Grenadines to supplement drinking water supplies (Peters 2012). The cost of water can be as much as US$38.00/m^3 (Peters, 2012). Further, the impact on agriculture, due to the drying up of ponds and low yields from wells, results in a loss of livestock, and low crop yields (primarily citrus, breadfruits, and coconuts). During severe dry seasons, the island has lost up to 30% of livestock (Government of Grenada, 2000).

Droughts are distinguished from other natural hazards in that there is slow-onset of the hazard. In the islands, the annual dry seasons, which may have characteristics of droughts, must be differentiated from actual droughts. Drought must be considered a relative rather than an absolute condition (WMO, 2006). Meteorologists monitor the extent and severity of droughts in terms of rainfall deficiencies. Agriculturalists rate the impact of droughts on primary industries; hydrologists compare ground water levels: and sociologists define it in terms of social expectations and perceptions (Bureau of Meteorology, 2012). Drought is not simply low rainfall, as the use of such a definition would result in classifying the Grenadines, when compared to the main islands of St. Vincent or Grenada, to be in almost perpetual drought. In the Grenadines these prolonged, abnormally dry periods can last for more than a year and have a return period of 3 to 6 years.

While regular, severe dry seasons, and to a lesser extent droughts, have been experienced in the Eastern Caribbean, the abitlity to manage and adapt to such events in the region has not been well developed. This is partly due to the absence of research on the annual dry seasons that sometimes are extended into droughts; and on the management of these occurrences in the Caribbean. To reduce the negative consequences of extended dry seasons, particularly on islands that have relatively low annual rainfall and depend primarily on rainwater harvesting, there is need for a better understanding of the drought and dry season hazard and the factors that influence the islands' vulnerability to this hazard. When a dry season or a drought occurs, the public is generally interested in the duration of the drought, the magnitude of the water deficit and the amount of rainfall that is needed for the return to normal conditions. Such information is useful where it is necessary to improve the quality of local and national responses to the dry seasons in the Grenadines. However, a better classification of these dry seasons based on an appropriate index is needed.

The 2009-2010 drought in the Caribbean heightened the interest in drought and drought management at the national and regional levels. It exposed severe deficiencies in the region's ability to cope with drought (Farrell et al., 2010). Trotman and Farrell (2010) described an initiative for assessing drought impacts and developing an early warning system for the Caribbean. Peters (2012) proposed a drought monitoring tool for the Grenadines. The tool is based on monthly rainfall measurements on the islands to establish relationships between rainfall deficiency and a projected severity of water shortages at the households' RWH storage facilities. The information can assist government and households to assess the current water situation, thereby providing an early indication of the need for contingency action or water shortage relief.

The on-going research in the region to improve the understanding and monitoring of rainfall extreme events is critical to the region's initiatives in developing adequate adaptation and mitigation measures to combat the impacts of climate change. These research efforts are generally based on using climatic information, namely rainfall, to establish drought indices. It is also important to understand how climate change is impacting on the nature of dry seasons.

This paper aims to contribute to the general research efforts by analysing the distribution of annual low rainfall in the Grenadines and by proposing a new methodology for measuring the severity of dry seasons and droughts for these small islands. Dry season severity is an essential component for presenting a comprehensive picture of the changing nature of dry seasons, particularly in an era of climate change. Further, it can be used to classify dry seasons in the islands and can be used to map the impacts of a dry season to its severity. The proposed dry season severity index would be based on the well-established standardised precipitation index (Mckee et al., 1993) and uses precipitation data from the Grenadines.

2. Drought Indices

In continental regions of the world, where there is comprehensive weather and climate monitoring infrastructure, policy makers and relief agencies can rely on several tools, including satellite-derived drought indicators and maps, in their decision making. Drought indices are the integration of one or more climate or hydrological variables (e.g., precipitation, temperature, soil moisture, streamflow and groundwater levels) on a quantitative scale (Steinemann et al., 2005). At present there are two broad groups of drought monitoring methodologies--(a) indices based on water balance calculation; and (b) statistical indices based on time series analysis. The water balance methodology requires application of several climatic and physical variables at a given time and space with the final goal being to determine the water deficit of the crop. On the other hand, statistical indices are based on one or occasionally two parameters, which are rainfall and temperature. When rainfall is the sole parameter, almost all current statistical drought indices use a simple summation of precipitation.

At least thirteen (13) drought indices for the United States of America have been developed since the early 1900s (Heim, 2002). These traditional indices have been used to measure how much precipitation, for a given period of time, has deviated from the historically established norms. Although none of the major indices is inherently superior to the rest, in all circumstances, some indices are better suited than others for certain uses (Hayes, 2007). In the United States, the Palmer Drought Severity Index, PDSI had been used to trigger drought relief programmes (Palmer, 1965). The derivative of the PDSI, the Crop Moisture Index (Palmer, 1968) is used to identify potential agricultural droughts. The Surface Water Supply Index (Shafer and Dezman, 1982), which represents water supply conditions unique to a particular watershed, was developed to incorporate both climatological and hydrological features into a single index value resembling the Palmer Index. The Keetch-Byram drought index (KBDI) (Keetch and Byram, 1968) was designed specifically for fire potential assessment. The KBDI is a continuous reference scale for estimating the dryness of the soil and duff layers. The index increases for each day without rain (the amount of increase depends on the daily high temperature) and decreases when it rains.

The Standardised Precipitation Index (SPI) (McKee et al., 1993), which could be computed for different time scales, can provide early warning of drought and help assess drought severity, and is less complex than the PDSI (Hayes, 2007). Vicente-Serrano et al. (2012), in a global assessment of the performance of different drought indices for monitoring drought impacts, found that the SPI drought indices had superior capability compared to the PDSI. However, the Standardised Precipitation Evapotranspiration Index (SPEI) was recommended instead of the SPI where the responses of the variables associated with droughts are not known *a priori* (Vicente-Serranoet al., 2012). In the Caribbean, the SPI is currently used by the Caribbean Institute of Meteorology and Hydrology for monitoring drought in the region (CIMH, 2012).

In an attempt to improve the results from individual indices, Balint and Mutua (2011) proposed a new index that combines six different established indices and reported good results in clearly identifying previous droughts in parts of Africa where drought data were absent. The incremental benefits from the additional complexities are however not clear. Byun and Wilhite (1999), in discussing weaknesses of current indices, noted that defining the period of the water deficit is important because the time when the water deficit period began and how long it lasted are critical to the level of impacts.

For many small islands, existing drought indices are often not appropriate for monitoring or describing severe dry periods and droughts. The water balance methods are far too complex and require a large quantity and many types of data that are not available. On the other hand, while the statistical indices may be more suitable for small islands as they consider only one or two parameters, they do not consider the persistence of the stress periods.Also statistical indices require continuous data observation, without gaps, which are is available in many small islands. In considering some of the challenges, Alley (1984) and Olapido (1985) recommended the use of only the precipitation data for the purpose of the meteorological use. Using only precipitation data is suited to locations where other data are not always available, and where the most important use for a dry season (drought) index is in the management of water supply from rooftop rainwater harvesting.

For data scarce locations, it is important to select or develop an index that can meet the specific needs and available resources. This approach is particularly suited and advantageous in the case of the small islands which are dependent on rainwater harvesting (RWH) and monthly rainfall is the best rainfall data set available. An index based on such data restriction would have limited use. For example, it would be inappropriate for determining soil moisture deficiency in agriculture but would be more suitable in determining water resource deficiencies in reservoirs or other sources which are affected by the amount of longer-term precipitation.

3. Methodology

Annual dry season rains were analysed for different starting months (December, January and February) and different durations to obtain the mean dry season rainfall. Further, the annual dry season rains were fitted to probability density functions to determine the best fit for this data using EasyFIT (Mathwave Technologies, 2012) with Microsoft Excel.

Dry seasons were also analysed using the persistent deficit precipitation as described in Barlow et al. (2006). A deficit occurs when the observed monthly-average precipitation falls below the long-term median value at a given location. A severe dry season occurs when the number of consecutive months of precipitation deficits exceeds a threshold set at 75 percent of median (by calendar month). In this study the number of months considered were 2, 3, and 4. Another configuration was considered by taking 6 consecutive months in which the threshold was exceeded in at least 4 of these months.

4. The nature of dry seasons in the Grenadines

The most widely used definition of dry season for tropical climates is based on the Köppen Climatic Classification (KCC) (Peel et al., 2007) which defines a dry season month as one for which the average rainfall is less than 60 mm. Like most Caribbean islands, the Grenadines experience an annual dry season during January to May. However, a dry season may start earlier than January and/or end later than May with varying degrees of drought-like conditions. The rainfall during an average five-month dry season is about 26% of the annual rainfall. Table 1 shows the average and minimum total annual rainfalls for dry seasons of different durations and starting periods for the Grenadines. An analysis of rainfall records for the Grenadines shows that the driest continuous 6 months had a total rainfall of 125mm and occurred during December 2002 through to May 2003. Further, 60% of the driest 6 months (that is total rainfall over the period of less than 250mm) began in December.

Table 1. Average dry season rainfall (mm) in the Grenadines

	Starting month of dry season				
Length of dry season	*December*	*January*	*February*	*March*	*Minimum*
4 months	221	168	165	242	42
5 months	260	231	280	-	94
6 months	316	337	-	-	125

Frequency distribution analyses of annual dry season rainfall in the Grenadines show that Log-normal and Log-Pearson distributions best fitted the data. Table 2 shows the probability distributions for total dry season rainfall in the Grenadines. Examples of the frequency density functions and fitted parameters are shown in the Appendix 1.

Table 2. Probability Distributions for total Dry Season rainfall in the Grenadines

Dry season period	Distribution type	Parameters
4 month	Log-normal 3P	σ=0.13189 μ=6.0407 γ=-255.6
5 month	Log-normal 3P	σ=0.09735 μ=6.784 γ=-627.76
6 month	Log normal	σ=0.35558 μ=5.6845

5. Classification of dry seasons in the Grenadines

The total rainfall during annual dry seasons can vary widely and is only mildly correlated to the total annual rainfall. A correlation coefficient of 38% was found between the total annual rainfall and total dry season rainfall. Dry seasons may be classified according to the duration, the water deficit and the potential impacts. Table 3 depicts the classification of dry season in the Grenadines. Such classifications can be developed for duration-specified dry seasons using the basic statistics of the Annual Dry Season Rainfall (ADSR). The January to May dry season's mean ($MEAN_{ADSR}$) and standard deviation STD_{ADSR} were used to develop a classification of five (5) categories. These are:

Table 3. Classification of dry season in the Grenadines

Dry season classification	Total rainfall (mm)	Probability	Impacts	Some coping mechanisms
Extreme	Less than 150	10%	Widespread household water shortage Drying up of RWH ponds Livestock death from thirst Loss of tree crop trees	Water importation Water conservation Widespread curling of livestock population
Serious	151 to 192	28%	Water shortage at households with small storages	Use of communal cisterns Use of water from dug wells Water conservation Sharing of water Some curling of livestock population
Normal	193 to 280	42%	Intermitted shortages at households	Use of communal cisterns by households with small storages Voluntary redistribution of household water supplies
Moderately wet	280 to 310	14%	Little household water shortage	Little redistribution Insignificant use of communal
Wet	Above 310	6%	Little household water shortage Early planting season	Little use of communal cisterns

Extreme = $(MEAN_{ADSR} - 1.0STD_{ADSR})$;
Serious = $(MEAN - 1.0STD_{ADSR})$ to $(Mean - 0.5 STD_{ADSR})$;
Normal = $(MEAN \pm 0.5STD_{ADSR})$;
Moderately Wet = $(MEAN + 0.5STD_{ADSR})$ to $(Mean + 1.0 STD_{ADSR})$; and
Wet $\geq (Mean + 1.0STD_{ADSR})$.

Such a classification is independent of how the rain is distributed during the dry season, and of the amount of rainfall in the preceding and succeeding periods. These factors influence the severity of the impacts of a given dry season. Figure 1 shows the total ADSR (for a duration of five months starting in January), ordered from low to high, for the Grenadines for past 50 years. About 10% of the dry seasons are in the extreme category.

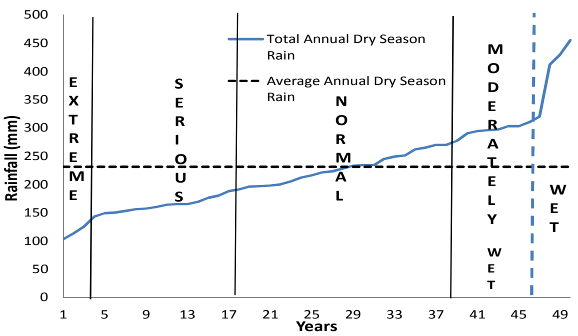


Figure 1. Classification of historic dry seasons for the Grenadines

6. Assessing the severity of dry seasons during the El Nino in the Grenadines

The Southern Oscillation (ENSO) is a natural phenomenon resulting from the fluctuations of ocean and atmospheric conditions in the Pacific between El Niño (warming) and a drop in temperature in the tropical Pacific known as La Niña. Since 1990, extreme dry seasons and droughts in the Caribbean are strongly influenced by El Nino (Farrell et al., 2010). This observation is confirmed in the case of the Grenadines where drought conditions were experienced in nine out of 20 El Nino years as shown in Table 4. The El Niño years as determined by COAPS (2012) and anecdotal evidence obtained through interviews with elderly islanders. It shows that the most remembered severe dry seasons (droughts) coincided with 45% of the El Niño years.

Table 4. El Nino years with severe dry seasons in the Grenadines

Year	Extreme Dry season	Year	Extreme Dry season
1918	No	**1972**	Yes
1925	No	**1976**	No
1929	Yes	**1982**	Yes
1930	No	**1986**	No
1940	No	**1987**	No
1951	Yes	**1991**	Yes
1957	Yes	**1997**	Yes
1963	No	**2002**	No
1965	No	**2006**	No
1969	Yes	**2009**	Yes

The El Nino fluctuations are irregular, but tend to appear every three to six years (UNEP-GRID, 2012). In the case of the Grenadines, the severity of the dry season appears to be impacted by the time in the year of onset, the duration and intensity of the El Niño event. When the event begins early in the rainy season, there is a tendency for the impacts of the water deficits during the following dry season to be more acute since that dry season would be following a 'dry' wet season. If the El Niño event starts during the dry season the water deficit preceding the dry season is low as the rainy season would have been normal or above average. The droughts and severe dry periods are expected to increase in frequency and intensity due to the effects of climate change according to UN-IPCC (2007).

7. Persistent deficit precipitation of dry seasons

The severity of a dry season in the Grenadines was analysed by using the Persistent Deficit Precipitation (PDP). Figure 2 shows the PDP for Carriacou. Over the period 1965-2011, 15% monthly rainfall was below a threshold of 50% of the monthly median. Ideally, the best use of the PDP for analysing the severity of dry seasons and drought is to consider consecutive months below a defined threshold. However, during a severe dry season it is possible for one month with uncharacteristically high rainfall to fall between months which satisfy the defined threshold.

Such significant rainfall during the dry season can have significant positive impact on household water supply, but have little impact on agriculture and livestock particularly if the rains fall in a cluster over a few days. To incorporate such a scenario in the analysis of dry seasons, a defined PDP threshold for 4 out of 6 months was used. Figure 3 shows the probabilities of PDP using two, three and four consecutive months and four out of 6 months. During any dry season there is a probability of one in two that the rainfall in at least two consecutive months would below 50% of the median.

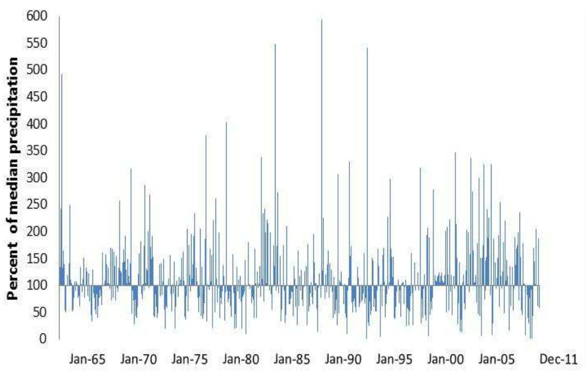


Figure 2. Persistent deficit precipitation for Carriacou

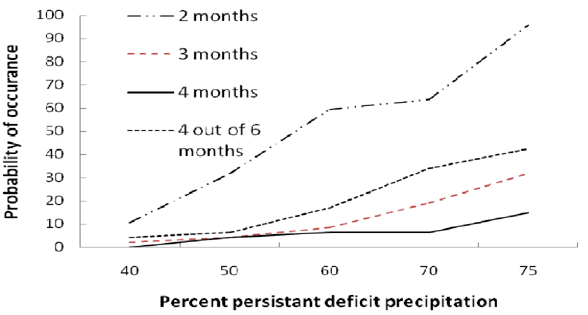


Figure 3. Probability of occurrence for threshold levels of deficit

8. Assessing the severity of dry seasons using the standardised precipitation index in the Grenadines

Droughts occur when there is a deficiency in available fresh water compared to some climatological mean over a predefined period (Byun and Wilhite, 1999). Consequently most of the current indices including the SPI assess droughts in these terms. A method of assessing droughts which also considers duration would be an improvement as the commencement of the water deficit period and how long it has lasted are very important concerns for islanders.

The severity of a dry season event is represented by the sum of all the SPI values ($\sum_{n=1,n} SPI$) for all the months during which the event occurred (Edwards and McKee, 1997). The sum of the SPIs for dry seasons associated with some El Niño years are shown in Table 5. In comparison with past dry seasons in the Grenadines, it was found that the 2010 dry season was the severest on record based on the summation of SPIs.

Table 5. SPI analysis for the KCC Dry Seasons for selected El Niño years in the Grenadines

	3-mth SPI	4-mth SPI	5-mth SPI	6-mth SPI	8-mth SPI
Average	*-3.70*	*-0.91*	*-2.01*	*-0.92*	*1.93*
1929	-5.06	-3.02	-1.41	-3.58	-0.70
1951/2	-4.0	-1.77	-4.83	-2,65	-1.5
1997	-6.56	-5.26	-3.89	-3.95	-0.09
2002	-2.69	1.13	-2.11	1.66	5.56
2009/10	-7.7	-3.13	-8.42	-7.42	-6.88

Assessing dry seasons, for the period based on the KCC, does result in a comprehensive analysis of the dry season event. The assessment of that period does not take into consideration the case of extended dry seasons that is, in cases where KCC defined dry season months precede or follow the normal dry season period (i..e, January to May). To overcome this, a dry season can be defined as a continuous period (T_{Event}) in which the SPIs remain negative (i.e., SPI dry season).

Using this definition, the analysis of the historic dry seasons was carried using the 4-month SPIs ($SPI_{4\text{-month}}$) and 6-month SPIs, ($SPI_{6\text{-month}}$) and the results are shown in Table 6. These results show that the values SPIs for 2010 varied far from the average. Table 7 shows that there is a strong correlation between the cumulative SPIs and the duration of corresponding dry seasons. As the cumulative SPI only partly describes the severity of the dry seasons in terms of water deficit, it is not sufficient as the duration of a dry season can influence the impacts of the dry season and the decision making required in mitigating these impacts.

Therefore, the measure of severity using only the summation of SPIs can be somewhat misleading. Managing negative impacts of a particular dry season is influenced by both the summation of the SPIs ($\sum_{n=1,n} SPI$) where n, is the number of months, and the duration of the dry season.

Table 6. Analysis of dry seasons based on continuous negative monthly SPI

	Mean absolute value SPI dry season (1931-2010)	Standard Deviation for all dry seasons (1931-2010)	Absolute value for 2010 dry season
SPI $_{4\text{-month}}$	5.43	2.82	10.91
SPI $_{6\text{-month}}$	5.37	3.72	13.69
$T_{4\text{-month}}$	5.96	2.64	9
$T_{6\text{-month}}$	5.91	3.34	14

Table 7. Correlation between 4- and 6-month SPI and duration of dry season for Carriacou

	SPI $_{4\text{-month}}$	**SPI $_{6\text{-month}}$**	**T $_{4\text{-month}}$**
SPI $_{6\text{-month}}$	0.97	1.00	Na
T $_{4\text{-month}}$	0.91	Na	1.00
T $_{6\text{-month}}$	Na	0.95	0.90

This is important in cases where water supply is dependent on RWH, as in the case of the Grenadines, where decisions for responding to water shortages are influenced by the deficit in an individual month and the duration of the deficit. This measure of severity can be improved by combining both the summation of the SPIs and the duration in one index. A Dry Season Severity Index (DSSI) is proposed in Equation 1 which combines the two variables. This proposed index is given by:

$$DSSI_n = \frac{\sum_{i=1,n} SPI_i \times T_{event}}{\overline{SPI} \times \overline{T}} \quad \text{Equation ...1}$$

where SPI_i is the individual monthly SPI during the event

T_{event} is the number of months during which SPI is continuously negative

$\overline{SPI}$ is mean value of the dry season cummulative SPI

$\overline{T}$ is the mean value of the during of Dry season (ie period when the SPI is continously negative

n is the number of months that SPIs is cummulated

Fifty years (1961-2011) of annual rainfall data was analysed for this new proposed DSSI and a summary of the results is shown in Table 8. The values of DSSI are in the range zero to ten, where values towards zero indicate a wet and/or a short dry season while large values of DSSI indicate extreme monthly deficits and/or a long period of low rain. The results from the DSSI show that the ranking of the five most severe dry seasons changes slightly from that using the summation of the SPIs (see Table 9). The severity of the dry seasons of 1931 and 1959 was confirmed, through anecdotal evidence obtained from interviews with elderly residents who recalled severe hardships due prolonged water shortages, high loss of livestock and poor crop yields.

Table 8. Summary of DSSI analysis for dry seasons in the Grenadines

Index	Mean value	Standard Deviation	Dry season 2010
$\overline{SPI}_{4-month}$	5.43	2.82	10.91
$\overline{SPI}_{6-month}$	5.37	3.72	13.69
$\overline{T}_{4\text{-month}}$	5.96	2.64	9
$\overline{T}_{6-month}$	5.91	3.34	14
$DSSI_{4-month}$	1.21	1.33	3.04
$DSSI_{6-month}$	1.37	1.72	6.04

Table 9. The most severe dry seasons in the Grenadines

Severity Order	$\overline{SPI}_{4-month}$	$\overline{T}_{4\text{-month}}$	$\overline{SPI}_{6-month}$	$\overline{T}_{6-month}$	$DSSI_{4-month}$	$DSSI_{6-month}$
1	1931	1931	1931	1931	1931	1931
2	1959	2010	2010	2010	1959	2010
3	2010	1959	1959	1959	2010	1959
4	1997	1947	1997	1997	1997	1997
5	1995	1997	1998	1998	1948	1947

9. The 2009/2010 Dry Season

During the 2009/2010 drought, the driest 4-month dry season (i.e., January to April), the second driest 5-month dry season (i.e., December to April) and the driest 6-month dry season (i.e., December to May) were recorded with a total rainfall of 42mm, 94mm and 125mm, respectively. Based on the fitted log-normal distributions for ADSR, the 2009/2010 dry season appears to be a rare event with small probabilities of occurrences of 0.0003, 0.0006 and 0.0007 for 4-month, 5-month and 6-month dry seasons respectively. These probabilities are unexpectedly high since there were at least two such events occurred during the past 100 years. This can partly be explained by the assumed distribution, which is based on a best fit and is likely to change with a larger data set. Nonetheless, it is an indication that the 2009/2010 event may indeed, have been a rare event. The total rainfall during the dry season over the last decade appears to be declining as shown by the linear trend line in Figure 4: This is consistent with projections made on the impact of climate change in the Southern Caribbean which suggest a pronounced north-south gradient in rainfall change during the Caribbean dry season (Trotz, 2008). Too much cannot be placed on the result of this study since the trend line is much different when values for 1999, 2000 and 2010 are excluded.

Based on the 4-month SPI, the 2010 dry season was the second in severity to the 1931/1932 dry season. Based on the duration of the dry seasons, 2010 was the third severest in history with 1931/1932 (16 months) and 1959 (11 months) respectively being more severe. Based on the 6-month SPIs, the 2010 dry season was second most severe considering the cumulative SPIs and the duration of the dry seasons.

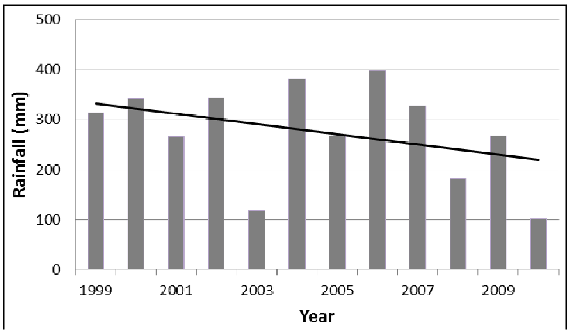


Figure. 4. Five-month dry season (December to April) rainfalls for the Grenadines

Based on the PDP, the driest consecutive four months and six months and the second driest consecutive five months were recorded during the 2009/2010 drought. During a period of nine consecutive months of below median rain, there were six of these months when the monthly precipitation fell below 50% of the median (see Figure 5). This was the longest continuous period, on record, of below median rainfall.

Based on the $DSSI_{4\text{-month}}$ analysis, the drought of 2009/2010 was the third worst and it was the second worst using $DSSI_{6\text{-month}}$. From the analysis, the 2009/2010 dry season (drought) was one of the top two severest in the history of the islands.

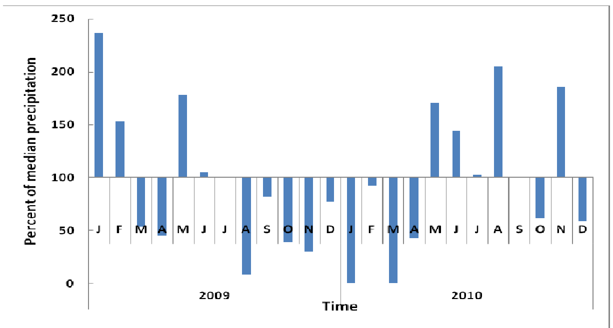


Figure 5. Persistent deficit Precipitation for 2009/2010 Drought in the Grenadines

10. Conclusions

While dry seasons in the Grenadines are annual events, the severity varies, and in some cases an extended dry seasons can become a drought. The analysis presented provides greater understanding of the nature of dry seasons in the islands. Measuring the severity of dry seasons can be a useful tool for water-supply planning as it can be used for developing management frameworks suited to the mitigation of the impacts of regular water shortages and for the promotion of agriculture and livestock development on the islands. Information on the probability of severe dry seasons can be useful to the design of rainwater systems and for analysing the vulnerability of the islands' water resources, particularly in the face of climate change.

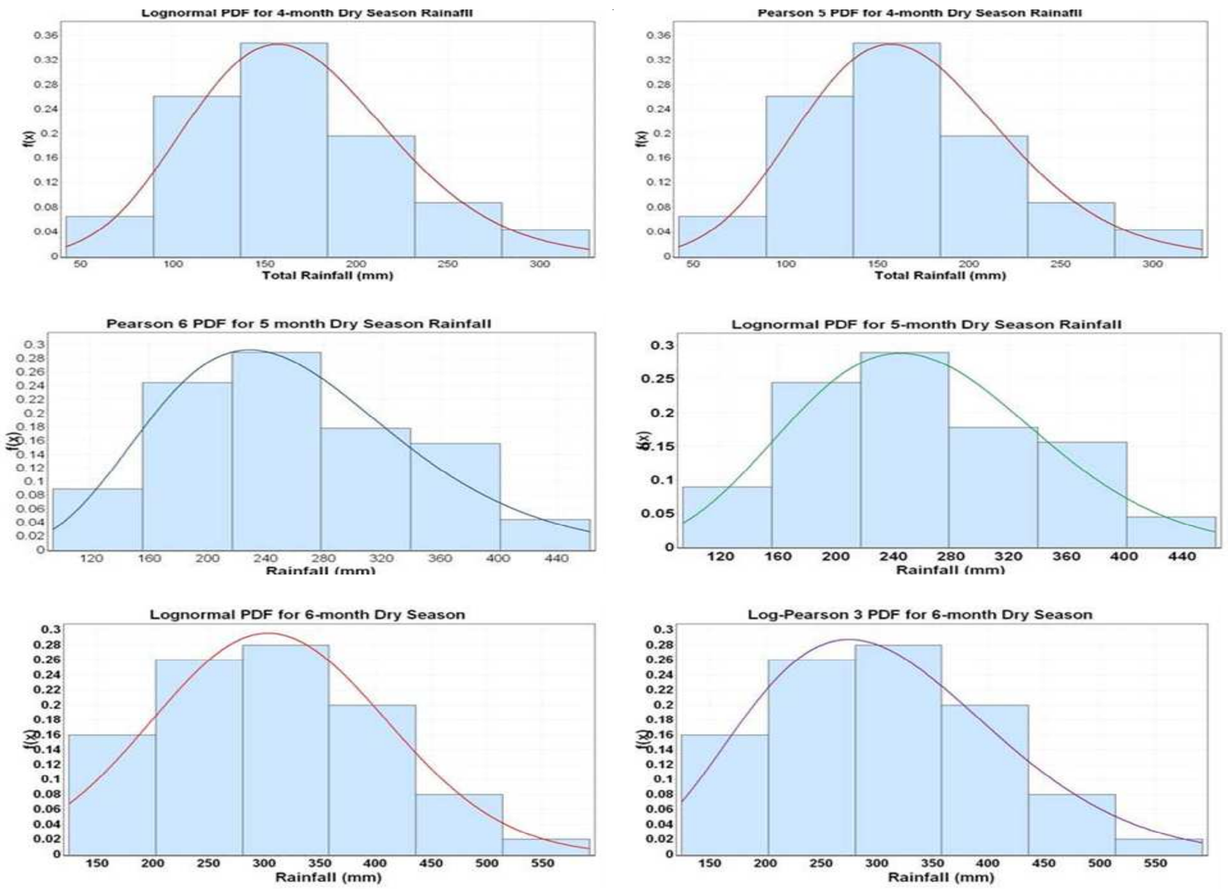
The total annual dry season rainfall best fits a log-normal distribution. The use of PDP for analysing the severity of dry seasons suggests that the probability of three and four consecutive months and four out of six consecutive months is less than 10% at a threshold of 50% median precipitation. This approach describes a severe dry season in the Grenadines.

While using the summation of SPIs for ranking dry seasons is suited to the islands where only rainfall data is available for long periods, the SPI may not adequately incorporate for the duration of the dry season. The monthly SPIs during the 2009/2010 dry season remained negative for 14 months, which made it the second longest dry season or drought on the islands for the past 80 years. The DSSI, which is a modification of SPI, is proposed as an improvement to the summation of SPI as it takes into consideration the duration of the dry season. This index was applied to the recent 2009/2010 dry season (drought) and it showed that the 2009/2010 dry season was one of the two severest in the past 80 years.

More extensive work on the use of the DSSI is required for other hydrological and geographic areas to confirm its robustness. It would also be useful to be able to identify some common impacts associated with different values of DSSI. In associating drought impacts with the severity index, one must also consider the ability of the community to withstand the event. Based on islanders' perception, the 2009/2010 drought might have appeared less severe due to the gains made in improving RWH storage capacities on the islands, and the improved access to imported water.

The apparent increase in severity of the dry seasons, which is consistent with recent research on the impact of climate change in the Caribbean, must be considered in adaptation to climate change programmes for the Grenadines. Specifically, programmes to promote the use of rainwater harvesting remain relevant in this context. Other alternative water supply sources, such as the use of solar powered desalination plants, like the one recently commissioned in Bequia, need to be pursued.

Appendix 1: Examples of the frequency density functions and fitted parameters



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