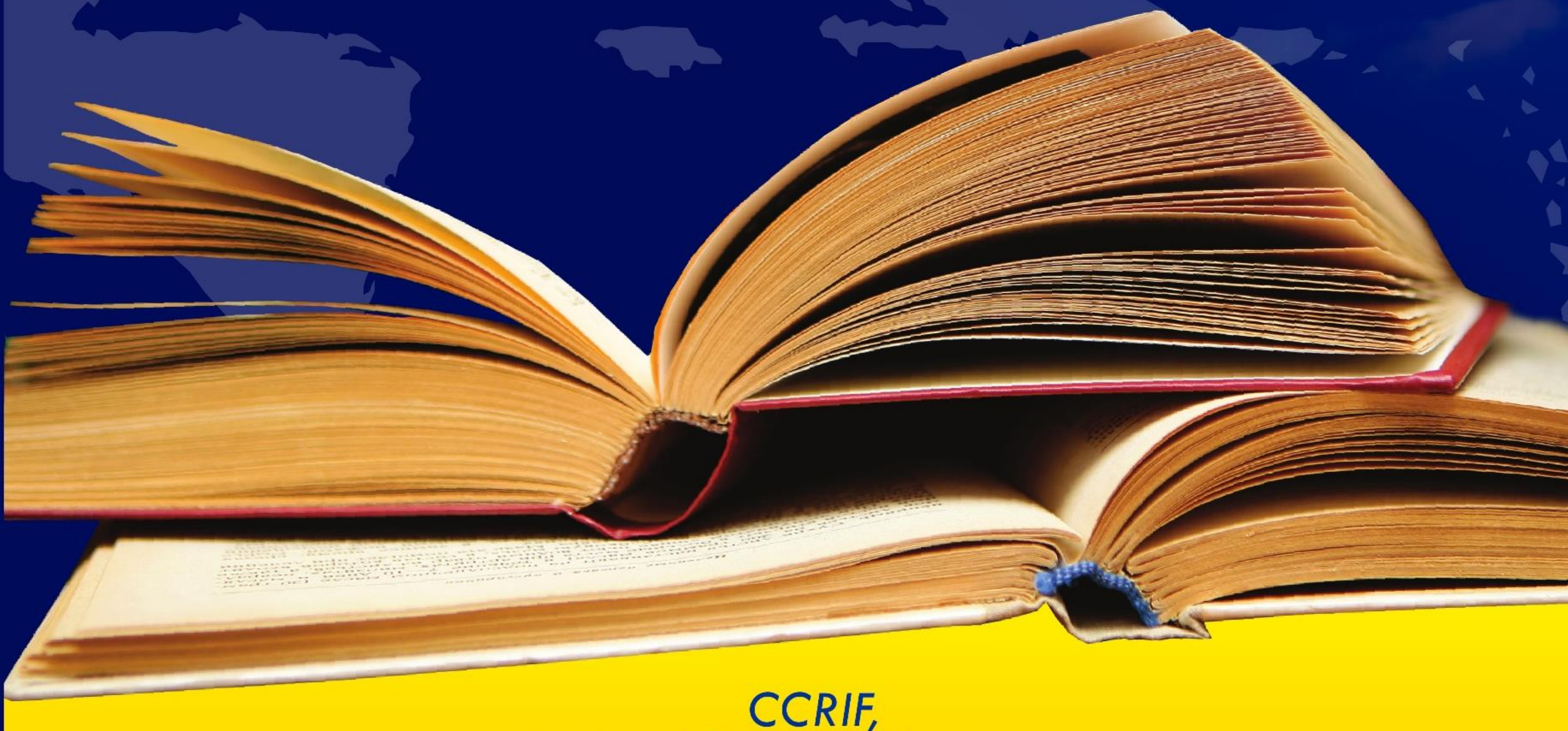
CCRIF SPC
The Caribbean Catastrophe Risk Insurance Facility

A Collection of Papers … Showcasing the Work of CCRIF Scholarship Recipients 2010-2012

CCRIF Technical Paper Series: Volume 3
September 2014



CCRIF,
A Natural Catastrophe Insurance Mechanism for the Caribbean

CCRIF: A Natural Catastrophe Risk Insurance Mechanism for the Caribbean

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MESSAGE FROM THE CHIEF EXECUTIVE OFFICER

I am pleased to present this third publication of technical papers, which focuses on work completed by recipients of CCRIF scholarships who have completed a Masters degree in areas related to disaster risk management.

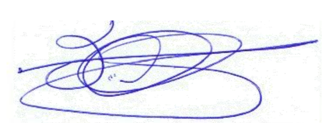
These scholarships are a key component of CCRIF's Technical Assistance Programme, which aims to help Caribbean countries deepen their understanding of natural hazards and catastrophe risk, and the potential impacts of climate change on the region.

The scholarship programme has been part of CCRIF's commitment to build capacity among the young people of the Caribbean to help create a core group of professionals who can provide assistance to the region in developing and implementing innovative disaster management and climate change adaptation strategies and programmes.

The theses and papers included in this publication demonstrate the high level of academic achievement by these students who have studied at universities in the United Kingdom, United States and the Caribbean. Also, we acknowledge the high quality work performed by these and other students in completing excellent group work – which is a major component of university disaster risk management programmes – but which is not included here.

We are pleased to note that recipients of CCRIF scholarships have gone on to work in the fields of environmental risk management, environmental engineering, disaster/emergency response, climate change policy, sustainable development and meteorology, among others.

The facility is committed to supporting the sharing of knowledge and experiences in disaster management through publications such as this. We pledge to continue our support of students in the region and to develop and implement programmes with our regional partners towards disaster and climate change resilience and sustainable development in the Caribbean.



Isaac Anthony
Chief Executive Officer

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Section 1

Background Information

About CCRIF

In 2007, the Caribbean Catastrophe Risk Insurance Facility was formed as the first multi-country risk pool in the world, and was the first insurance instrument to successfully develop parametric policies backed by both traditional and capital markets. It was designed as a regional catastrophe fund for Caribbean governments to limit the financial impact of devastating hurricanes and earthquakes by quickly providing financial liquidity when a policy is triggered.

In 2014, the facility was restructured into a segregated portfolio company (SPC) to facilitate expansion into new products and geographic areas and is now named CCRIF SPC (CCRIF). The new structure, in which products are offered through a number of segregated portfolios, allows for total segregation of risk. CCRIF SPC is registered in the Cayman Islands and operates as a virtual organisation, supported by a network of service providers covering the areas of risk management, risk modelling, captive management, reinsurance, reinsurance brokerage, asset management, corporate communications an information technology.

CCRIF currently offers earthquake, tropical cyclone and excess rainfall policies to Caribbean governments and will soon offer loan portfolio coverage to financial institutions in Caribbean countries.

CCRIF helps to mitigate the short-term cash flow problems small developing economies suffer after major natural disasters. CCRIF's parametric insurance mechanism allows it to provide rapid payouts to help members finance their initial disaster response and maintain basic government functions after a catastrophic event.

Since the inception of CCRIF in 2007, the facility has made nine payouts for hurricanes, earthquakes and excess rainfall totalling almost US$33 million to seven member governments. All payouts were transferred to the respective governments within 14 days (and in some cases within a week) after the event.

CCRIF was developed under the technical leadership of the World Bank and with a grant from the Government of Japan. It was capitalised through contributions to a multi-donor Trust Fund by the Government of Canada, the European Union, the World Bank, the governments of the United Kingdom and France, the Caribbean Development Bank and the governments of Ireland and Bermuda, as well as through membership fees paid by participating governments.

Sixteen governments are currently members of the facility: Anguilla, Antigua & Barbuda, Bahamas, Barbados, Belize, Bermuda, Cayman Islands, Dominica, Grenada, Haiti, Jamaica, St. Kitts & Nevis, Saint Lucia, St. Vincent & the Grenadines, Trinidad & Tobago and Turks & Caicos Islands.

CCRIF Vision Statement

- A Caribbean region with optimised disaster risk management and climate change adaptation practices supporting long-term sustainable development

CCRIF Mission Statement

- Our Mission is to assist Caribbean governments and their communities in understanding and reducing the socio-economic and environmental impacts of natural catastrophes.

CCRIF Value Proposition

The clients of CCRIF are the member countries of the Caribbean Community (CARICOM). CCRIF promises its clients to:

- Fill a gap in available insurance offerings in natural catastrophes
- Give peace of mind and confidence re financial support
- Provide technical assistance to enhance disaster risk assessment
- Assist them to better understand how risk financing fits into the broader disaster risk management framework
- Offer the lowest possible premiums consistent with long-term sustainability
- Ensure speedy payout when a policy is triggered
- Be transparent and accountable

Strategic Objectives

- To provide products, services and tools responsive to the needs of the region
- To enhance capacity for disaster risk management and climate change adaptation
- To sustain corporate and financial integrity
- To deepen understanding and knowledge of catastrophe risk and the solutions CCRIF provides

THE CCRIF TECHNICAL ASSISTANCE PROGRAMME

CCRIF launched its Technical Assistance (TA) Programme in 2009 to help Caribbean countries deepen their understanding of natural hazards and catastrophe risk and the potential impacts of climate change on the region. It provides an ongoing mechanism for grant support within the Caribbean region for capacity building initiatives and the development and implementation of projects which have a strong potential for improving the effectiveness of risk management. The TA Programme has three components as follows:

Scholarship/Prof. Dev. Programme	Regional Knowledge Building	Support for Local DRR Initiatives
• Students across the region to benefit • Scholarships for BSc and MSc programmes • Continued professional development	• Partnerships with regional institutions • Funding for regional technical projects in natural hazards/risk science	• Support for NDCs, NGOs and other community-based organisations in local hazard risk management and climate change initiatives

The Scholarship/Professional Development Programme is designed to help create a cadre of professionals to play a key role in developing national and regional strategies that will lead to improved disaster risk management and increased climate change resilience. Within this component, CCRIF provides scholarships to persons pursuing degrees in areas related to disaster risk management in the United Kingdom, United States, Canada and the Caribbean.

Areas of Study for CCRIF Scholarships include:

- **Catastrophe risk management**
- **Climate Change**
- **Sustainable development**
- **Meteorology**
- **Disaster management**
- **MBA with risk management**

Since 2010, the facility has awarded 25 scholarships to Caribbean nationals either through the CCRIF Scholarship Programme or its University of the West Indies (UWI)-CCRIF Scholarship Programme. Total disbursements to date are in excess of US$430,000. Scholarship recipients have been nationals of Anguilla, Antigua & Barbuda, Barbados, Grenada, Guyana, Jamaica, Saint Lucia, St. Vincent & the Grenadines, and Trinidad & Tobago.

Ms. Wazita Scott conversing in August 2010 with Dr. Warren Smith, then Board Member of CCRIF (now President of the Caribbean Development Bank), at his office regarding her scholarship. Ms. Scott from St. Vincent and the Grenadines was awarded a grant to attend Reading University in the UK to pursue a Master of Science degree in Atmosphere, Ocean, and Climate.

CCRIF CEO, Mr. Isaac Anthony (2nd right), paid a courtesy visit on UWI Registrar, Mr. Clement Iton (1st left) in January 2013 and had the opportunity of meeting two of the CCRIF scholarship recipients for 2012/13, Herona Thompson (3rd left) from Jamaica and Carina Rouse (1st right) from Anguilla, both reading for Geography degrees at the Mona Campus. Also in the photo is Dr. Angella Stephens (2nd left) from the UWI undergraduate scholarship department.

CCRIF also provides support to regional and member government institutions from time to time to build capacity of key individuals in areas related to catastrophe and disaster risk management. A notable example of this assistance was the awards provided by CCRIF in 2011 to two individuals employed to Belize's National Meteorological Service to allow them to study for a Bachelor of Science degree in Meteorology at the University of West Indies, Cave Hill Campus, Barbados. In addition, CCRIF has provided support for professional development of persons in key regional organisations through their attendance at conferences and workshops.

Chairman of the CCRIF Board, Mr. Milo Pearson (2nd left), paid a courtesy visit to the Chief Meteorologist, Mr. Dennis Gonguez (2nd right) in August 2011 and met the recipients of the CCRIF fellowships, Ms. Michele Smith and Ms. Shanea Young (far left and far right respectively).

CCRIF provided support for Ms. Andrea Sealy (bottom left) from the Caribbean Institute of Meteorology and Hydrology to participate in an International Training Course on Satellite Meteorology in 2010 at the China Meteorological Administration Training Centre in Beijing.

Recipients of CCRIF scholarships are employed at institutions such as Guyana's Ministry of Natural Resources and the Environment, the Caribbean Institute of Meteorology and Hydrology and Jamaica's Ministry of Water, Land, Environment & Climate Change, among others, and work in the fields of environmental risk management, environmental engineering, disaster/emergency response, climate change policy, sustainable development and meteorology.

Testimonials from some of our scholarship recipients…		
"It is an honour to be the recipient of the Caribbean Catastrophe Risk Insurance Facility scholarship. I am pleased to inform you that I have successfully completed my degree with first class honours." *- Carina Rouse*	"I am very appreciative of the CCRIF-UWI scholarship I received in my final year at UWI Mona. The scholarship allowed me to realize that hard work and dedication is indeed the key to greatness." *- Odene Baker*	"Evaluating myself before and after the programme, the personal, academic and professional skills I've acquired and built on are tremendous. Personally, my self-confidence has grown and I feel accomplished and well rounded (as person and as a young professional in my field)." *- Annlyn McPhie*
"I find the programme challenging yet very enlightening, and I strongly believe that I will be better able to make a meaningful contribution to Jamaica's development after completing my studies, through the application of techniques to foster social advancement, economic development and environmental preservation in Jamaica." *-Sean Hylton*	"The opportunity afforded by the CCRIF Extra-Regional Scholarship was a privilege. Upon returning to Guyana, I was appointed to the post of Technical Officer for Climate Change in the Ministry of Natural Resources and the Environment [which] has enabled me to influence national climate policy decisions and to make an unflagging contribution towards environmental protection in Guyana through applying the knowledge and skills acquired from postgraduate studies." *- Mahendra Saywack*	"I am proud to be selected as Saint Lucia's first recipient of this prestigious award. I am appreciative of this opportunity because [it has allowed me] to pursue my aspirations, network and interact with students of diverse cultures, and undertake research in a specialist area which can be used for the betterment of risk management." *- Germaine Maxwell*

Section 2

The Technical Papers

LIST OF PAPERS

- **An Assessment of Tropical Cyclone Rainfall Characteristics within the Eastern Caribbean**
  Wazita Scott

- **Capacity Assessment Earthquake Unit, Mona, Jamaica**
  Anna Tucker

- **Climate Smart Agriculture: Can It Be Achieved?**
  Mahendra Saywack

- **The impact of hydro-meteorological hazards on crop production among small-scale farmers in Crofts Hill, Clarendon**
  Dorlan Burrell

- **Why is a hardware financing policy mechanism like the CDM inadequate to facilitate low carbon technology transfer to many developing countries?**
  Mahendra Saywack

The complete papers, including appendices, are available on the CCRIF website at www.ccrif.org/content/publications/student-papers-theses.

ABOUT THE AUTHORS

Dorlan Burrell

Mr. Dorlan Burrell is a Director within the Environment and Risk Management Division of the Ministry of Water, Land, Environment and Climate Change (Jamaica). He received an MSc in Natural Resources Management with a major in Disaster Risk Management at the University of the West Indies. Previously, he worked as the Disaster Risk Reduction Project Assistant for the Jamaica REEACH Project being implemented by ACDI/VOCA and funded by USAID. Also, Mr. Burrell has worked on an Oxfam GB funded project providing a road map for the Jamaican agricultural sector based on local knowledge of farmers and future climate projections. Mr. Burrell is currently working as the National Coordinator for a National Science Foundation project in Jamaica through the University of North Carolina.

Mahendra Saywack

Mr. Mahendra Saywack is the Technical Officer for Climate Change within the Ministry of Natural Resources and the Environment (Guyana). He joined the Ministry upon completion of an MSc degree in Climate Change and Development, from the University of Sussex, England, in 2013, graduating with distinction. Mr. Saywack holds a BSc degree in Environmental Studies from the University of Guyana and worked with the Environmental Protection Agency upon graduation. In his current position, Mr. Saywack is directly involved in policy planning and coordination of forestry-related policy initiatives (REDD+), as well as monitoring and evaluating the Natural Resources and Environmental Sector's obligations to various national and international agreements.

Wazita Scott

Ms. Wazita Scott is a Technical Officer at the Caribbean Institute for Meteorology and Hydrology (CIMH) where she is researching the downscaling of climatological and meteorological data for forcing eco-hydrological models. She currently lectures in Meteorology at CIMH and is a former lecturer at the University of the West Indies (UWI), Cave Hill Campus. She holds BSc degrees in Computer Science and Meteorology with a minor in Mathematics from UWI and an MSc degree in Atmosphere, Ocean and Climate from the University of Reading in the United Kingdom.

Anna Tucker

Ms. Anna Tucker is the Disaster Risk Management (DRM) Specialist within the Preparedness and Emergency Operations Division at the Office of Disaster Preparedness and Emergency Management (ODPEM), Jamaica. She received her BSc in Urban and Regional Planning from the University of Technology, Jamaica and completed an MSc in Natural Resources Management with a major in Disaster Risk Management at UWI. Ms. Tucker has revised national disaster management plans for Jamaica and developed numerous community disaster risk management plans, hazard maps and vulnerability and risk assessments. She is the focal point in ODPEM for the development of climate change adaptation strategies as part of the COMET II Project and is working with CIMH and the Caribbean Disaster Emergency Management Agency (CDEMA) for the development of a Climate Impact Database for the Caribbean.

An Assessment of Tropical Cyclone Rainfall Characteristics within the Eastern Caribbean

By Wazita Scott

This thesis was submitted in partial fulfillment of the requirements for the degree of Master of Science in Atmosphere, Ocean and Climate at the University of Reading.

Introduction

Tropical Cyclones (TCs) are known to be highly destructive, particularly when impacting populated regions, where the loss of property, life and livelihood can be devastating. In the last 150 years, the Eastern Caribbean was struck by 38 major hurricanes (≥ Category 3) and hundreds of tropical storms (CHN, 2013). The typically small size of the island states exposes a large proportion of the total produced capital to the risk of hydro-meteorological hazards like TCs (UNISDR, 2013). Therefore, it is no surprise that a major impact of repeated TCs in the Caribbean over the decades has been "sluggish" economic growth (UNISDR, 2013). The annual direct and indirect losses are approximately 6% of the gross domestic product (GDP) in some countries. These losses are anticipated to increase owing to climate change (Cavallo and Noy, 2010; Ghesquiere and Mahul, 2010).

Records show that more people die from storm surge and rainfall-induced hazards like floods and landslides resulting from TCs than from the associated strong winds. Accurate precipitation estimates are therefore essential for forcing hydrological models (Bastola and Misra, 2013) and predicting damage and loss (CCRIF, 2012). However, in the Caribbean, sparse monitoring networks and typically low measurement frequencies have created a data-scarce environment. Remote sensing and reanalysis products are alternative methods, which offer significant potential for supplementing measurements in data-sparse areas.

While remote-sensing products provide independent, reliable, real-time data, they are not as accurate as ground-based measurements. Routine use of these data to make defensible decisions requires that relationships be established with ground-based data (Scott, 2011). In other regions, estimates of precipitation from satellite and reanalysis products have been validated on daily (Sapiano and Arkin, 2009, Almazroui, 2011), monthly (Yilmaz et al., 2005; Villarini and Krajewski, 2008; Almazroui, 2011) and seasonal (Almazroui, 2011) time scales. However, to the best of our knowledge, none have been performed nor reported for the Eastern Caribbean (Scott, 2011). The objective of this study was to validate precipitation estimates from satellite and reanalysis data for TCs in the Eastern Caribbean.

Data and Methods

Study Area

The study area is the Eastern Caribbean, which consists of approximately 50 islands forming a 1,000-km arc at the eastern boundary of the Caribbean Sea. The island chain is in the hurricane-active zone of the North Atlantic basin. The precipitation regime is dominated by a summer wet season (June – November), which also coincides with a TC season that brings high winds and torrential rains.

Datasets

Archived rainfall data were obtained from 11 rain gauge stations on islands affected by the storms during the period 2004 to 2010 and used to validate satellite rainfall products and one reanalysis product. Data for this study were sourced from Hewanorra and George Charles in Saint Lucia; Maurice Bishop in Grenada; E.T Joshua in St. Vincent and Crown Point in Tobago. Martinique provided data from gauges at Lamentin, Morne Rouge, Ste-Anne, Saint-Pierre, Trinte and Vauclin (Figure 1). Owing to their proximity (7.8 km), the Morne Rouge and Saint-Pierre data were combined and averaged. With the exception of Martinique, data were 6-hourly accumulations starting at 12:00 UTC and obtained from a single gauge. Data from Martinique were 1-hourly accumulations from 6 tipping bucket rain gauges. Given the higher spatial and temporal resolution of the Martinique dataset, these data are the focal point of this analysis.

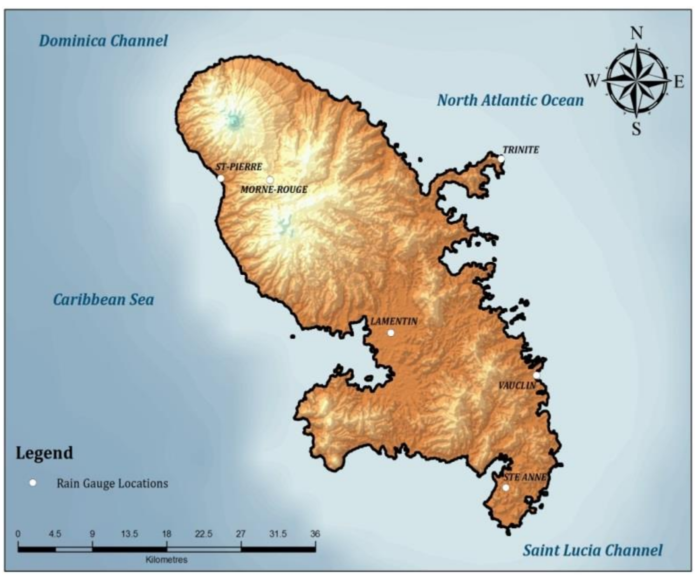

Figure 1. Map of Martinique showing the location of the ground-based monitoring stations.

Satellite data were sourced from the Tropical Rainfall Measuring Mission (TRMM) multi-sensor precipitation product (3B42) and the Precipitation Estimation from Remotely Sensed Information Using Artificial Neural Networks (PERSIANN) product. Reanalysis data were sourced from the European Centre for Medium-Range Weather Forecasts (ECMWF), ERA-Interim (ERA-I). The TRMM is a joint USA–Japan satellite mission for monitoring tropical and subtropical precipitation. Instrumentation is described by Kummerow et al. (1998) but the principal precipitation measuring instruments are the TRMM Microwave Imager (TMI) and the Precipitation Radar (PR). Algorithm 3B42 produces precipitation and root-mean-square error (RMSE) estimates on a 0.25° (~25-km) grid every 3 hours (Huffman et al., 2004). PERSIANN is an automated system developed to estimate precipitation from remotely sensed infrared imagery (Sorooshian et al., 2000). PERSIANN data are also generated on a 0.25° (~25-km) grid every 3 hours. The ERA-I is a global reanalysis of recorded climate observations for the period 1979 to present. Estimates of precipitation are available on a 0.75° (~75-km) grid from two forecasts which are produced every 3 hours initialized at 0000UTC and 1200UTC (Dee et al. 2011).

Tropical Cyclones

A total of 116 TCs traversed the North Atlantic basin during the period 2004 to 2010. Seven of these either made landfall or near landfall within the Eastern Caribbean. The TCs of interest were Hurricane Tomas (2010), Tropical Storm Erika (2009), Hurricane Dean (2007), Tropical Storm Felix (2007), Hurricane Emily (2005), Tropical Storm Earl (2004), and Hurricane Ivan (2004). Remotely-sensed precipitation amounts and reanalysis data associated with these systems were compared with the gauge data.

Analytical Procedures

The analysis is based on direct comparisons of ground-based measurements at gauge stations with station-centred precipitation estimates extracted over a 20-km radius (TRMM and PERSIANN) products or a 47.5-km radius (ERA-I). The gauge situated at the centre of the extracted domain represented the observed amount corresponding to the precipitation estimates. Rainfall estimates were extracted from the precipitation products at 3-hr intervals and spatially averaged for comparison with rain gauge data.

Different types of rainfall patterns can have significantly different statistical properties. The measures of central tendency were determined using histograms. The ordinary histogram is a function f_i that counts and graphs the number of observations occurring in discrete intervals as a representation of the probability distribution of a continuous variable. The histogram statistic was calculated as follows: the number of rainfall observations i = 1 to n, and k the total number of bins. Then by definition, f_i must satisfy:

$$n=\sum_{i=1}^{k}(f_i) \qquad (1)$$

The cumulative histogram, F_i, of histogram f_j, counts the cumulative number of observations in all of the bins up to some specified bin and is defined as:

$$F_i=\sum_{j=1}^{i}(f_j) \qquad (2)$$

Ordinary and cumulative histograms were derived for rain gauge, TRMM, PERSIANN, and ERA-I data using 2-mm/hr bins. Precipitation estimates from TRMM, PERSIANN and ERA-I were also regressed on observations and the coefficients of determination (R^2) determined for each gauge station. To quantify the performance, categorical statistics including threat score (TS), equitable threat score (ETS), and bias were calculated based on the contingencies in Table 1.

Table 1: Contingency table applied at each gauge

Event Estimated	Event Observed		
	Yes	No	Marginal Total
Yes	H	F	H + F
No	M	Z	M + Z
Marginal Total	H + M	F + Z	H+ M + F + Z = N

In Table 1, H is a hit, an event forecast to occur that did occur. M is a miss, an event forecast not to occur, but did occur. F is a false alarm, an event forecast to occur, but did not occur. Z is a correct negative, an event forecast not to occur that did not occur. In this context, an event is a threshold of interest. As an example, H would be the number of correct predictions of intensities above a specified threshold whereas Z would be the number of correct predictions of intensities below that threshold. Thresholds for light (0 – 2.5 mm/hr), moderate (2.5 – 10 mm/hr), heavy (10 -50 mm/hr), and violent (> 50 mm/hr) rainfall intensities (AMS, 2000) were used with Table 1 to evaluate skill in detecting storm types. The resulting tallies were used to calculate the treat score according to Stanski et al. (1989):

$$TS = \frac{H}{H + M + F} \quad (3)$$

The TS gives high scores for accurate (high skill) estimates. For a skilled estimator, H=1 and M=F=0 to yield a TS of 1. For an unskilled estimator, H = 0 to yield TS = 0. Owing to the sensitivity of the TS to the climatology of the events, it tends to give lower scores (low skill) for rare events. The equitable threat score corrects for this tendency and is simply a modification of the threat score that accounts for correct forecasts due to chance (Stanski et al., 1989):

$$ETS = \frac{H - H_r}{H + M + F - H_r} \quad (4)$$

where H_r = hits due to random chance and is given by:

$$H_r = \frac{(H + M)\ (H + F)}{N} \quad (5)$$

and N is the sample size. The ETS ranges from -1/3 to 1, with 0 indicating no skill and 1 being skilled. The bias compares the forecast frequency of events to the observed frequency and is defined as:

$$BIAS = \frac{H + F}{H + M} \quad (6)$$

BIAS ranges from 0 to ∞ and indicates whether the estimator has a tendency to under-forecast (BIAS<1) or over-forecast (BIAS>1) events. The root mean square error (RMSE) was used to quantify differences between estimates ($\hat{Y}_i$) and observations (Y_i), and was calculated as:

$$RMSE = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (\hat{Y}_i - Y_i)^2} \quad (7)$$

The RMSE is a good measure of accuracy; here it is used to compare forecasting errors of the precipitation products. It gives a relatively high weight to large errors so it is most useful when large errors are undesirable. The RMSE ranges from 0 to ∞, with a 0 being a perfect score.

Results and Discussion

Comparison of the 3-hr rainfall rates

The intensities obtained from satellite and reanalysis products during Hurricane Tomas (Tomas) are compared with gauge data from Lamentin in Martinique and are shown in Figure 2. The most striking observation is the difference in intensities. The gauge data show the highest rate (10.2 mm/hr), which is 1.4 times the rate recorded by the TRMM (7.07 mm/hr) and the PERSIANN (7.29 mm/hr) and 1.7 times the ERA-I rate (6.07 mm/hr). These differences are partly attributed to the differences in temporal resolution. While the rain gauge data were collected at 1-hr intervals, the products were reported every 3 hours. At the finer temporal resolutions (Figures 1a-c), the increase in maximum values is clear. This observation is consistent with the findings of Georgakakos et al. (1994) who reported a four-fold increase in intensity, from 30 mm/hr at a 10-min resolution to almost 120 mm/hr at 1-min and 10-sec resolutions.

Some of the discrepancies can also be attributed to differences in spatial resolution.

Undoubtedly, averaging of the ERA-I estimates over a larger area (47.5-km radius) versus the satellite products (20-km radius) contributes to greater smoothing and thereby a smaller peak and smaller variance (smoother curve) for the ERA-I data (Figure 1d). For mountainous regions of the tropics, the World Meteorological Organization (WMO) recommends 1 station for a 100 – 250 km^2 area whereas 1 station for a 250 – 1,000 km^2 is considered acceptable. Even then, a WMO standard rain gauge provides a point measurement of the distribution of a storm over a given area from an inlet diameter of 15.95 cm or orifice area of 200 cm^2. The footprint for TRMM and PERSIANN footprint is 625 km^2 and around 5 × 10^3 km^2 for ERA-I. Spatial variability in rainfall rates, especially during convective precipitation, may therefore introduce uncertainty into estimates of spatially-averaged rainfall that cannot be easily quantified with the sparse monitoring networks.

Finally, some inherent errors may be due to data quality. Tipping-bucket rain gauges are known to be affected by wind blockage, eddies, and wetting losses, all of which could

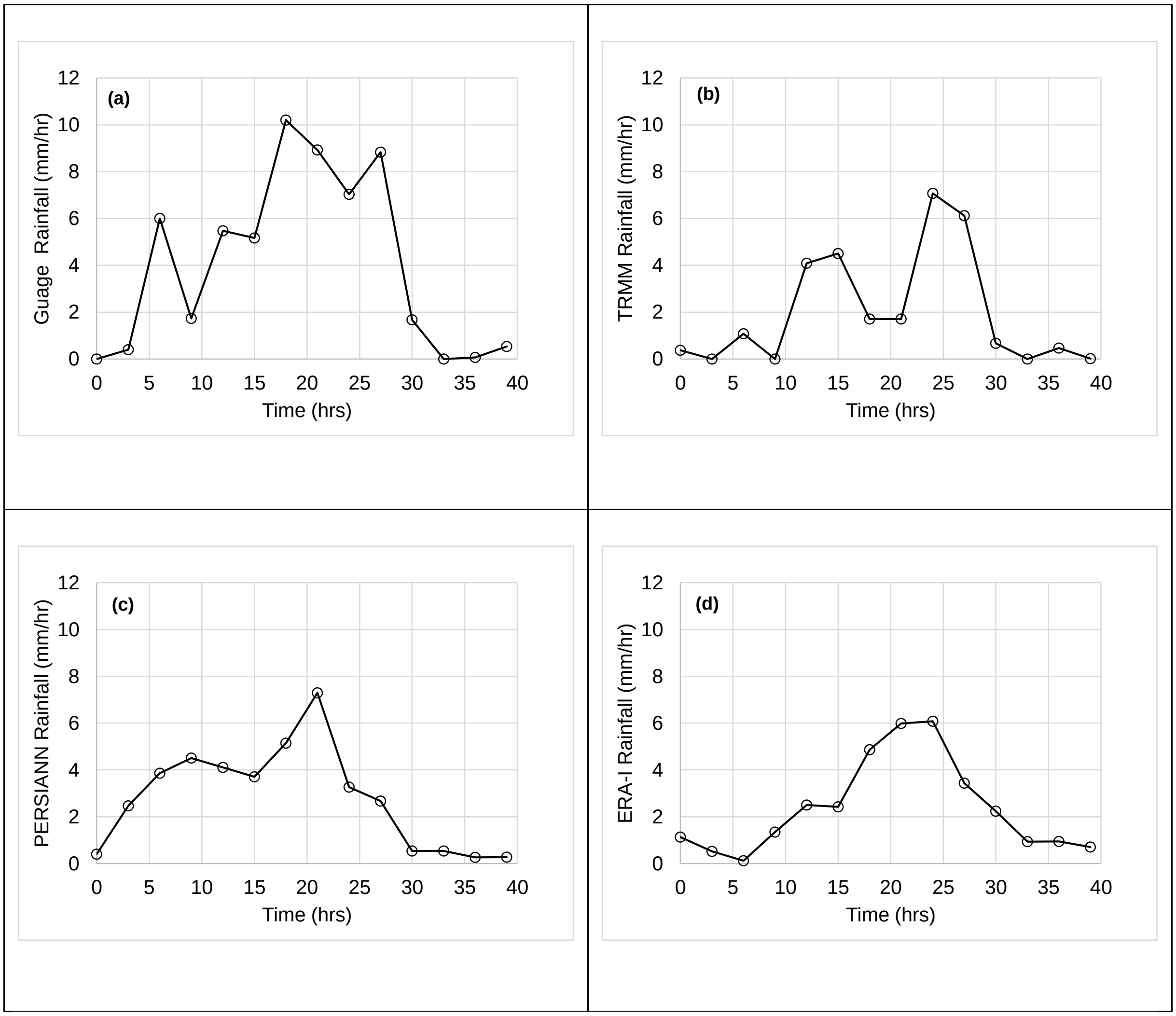

Figure 2: Temporal distribution of rainfall intensities during Tomas from: (a) rain gauge, (b) the TRMM, (c) the PERSIANN, and (d) ERA-Interim. Rainfall is averaged on a 3-hr interval.

be important during a TC. Uncertainty in satellite-retrieved estimates related to spatial and temporal sampling have been discussed by other authors (e.g. Bell and Kundu, 2000; Steiner et al., 2003, Bowman, 2005). In the context of the Eastern Caribbean, the 25-km spatial resolution and the 3-hr temporal resolution are still relatively coarse and could also add to the uncertainty in TRMM and PERSIANN estimates. Possible sources of errors in the ERA-I data include faulty measurements that were assimilated into the model.

Intensity differences translate into different total accumulations over the 40-hr monitored period. A comparison of the mean total accumulations shows significant differences between the gauges (168.08 mm) and the estimation products. For the same period, TRMM estimates totalled to 82.66 mm compared to 116.20 mm for PERSIANN and 97.31 mm for ERA-I. Such large differences in rates and depths have implications for parameterizing models for loss projection and weather-related hazards. These discrepancies will invariably increase the uncertainty in timing the onset and duration of the rainfall events and the impact of rainfall-induced hazards.

To determine the significance of the observed differences, statistical methods were used to compare the intensities. First, an F-test was conducted to test the null hypothesis that the variances were different. The F-test showed that the variance of the observations (14.30) was not significantly different (α =0.05) from the variance of the TRMM (5.92). However, the variance of the PERSIANN (4.72) and ERA-I (4.02) were both different from the observations. The large variance in the observations is attributed to the higher temporal resolution. To determine the significance of differences in the means, a two sample t-test was conducted, assuming equal sample variances (gauge vs. TRMM) and unequal variances (gauge vs. ERA-I). The t-test shows that the observed mean intensity (4 mm/hr) is not statistically different from the TRMM (1.985 mm/hr), the PERSIANN (2.79 mm/hr), nor ERA-I (2.37 mm/hr).

Probability Distributions of 3-hr rainfall rates

Figure 3 shows ordinary and cumulative histograms of rainfall intensity at 2-mm intervals for the rain gauge and precipitation products for Tomas. These plots represent all of the data collected at the six gauge stations in Martinique (N = 70). The observations and estimates show very different distributions. It is known that different types of rainfall patterns can have significantly different statistical properties. The most striking observation is the non-Gaussian distribution for the 4 products. If the zero intensities are ignored in the rain-gauge data the ordinary histograms all show a truncated distribution with the peak near the origin at 2 mm/hr and a gentle trailing off to intensities over 10 mm/hr.

This is indicative of a process in which part of the distribution has been removed through screening. In this case, intensities at a temporal resolution less than 1-hr have been effectively screened out. In the literature, rates have been reported to increase by a factor of over 4 in going from a resolution of 10-min resolution to 1-min (Georgakakos et al., 1994). These distributions are not at all surprising as one of the main statistical features of intense rainfall fields at spatial scales between about 1 and 200 km and temporal scales between a few minutes and several hours is that they have a non-Gaussian probability distribution of intensity both in space and time (Rebora et al., 2006). The choice of technique used for the measure of the central tendency, to estimate missing

dependence of the distribution on sampling resolution.

Figure 4 compares the 1-hr observations from Martinique during Tomas with the

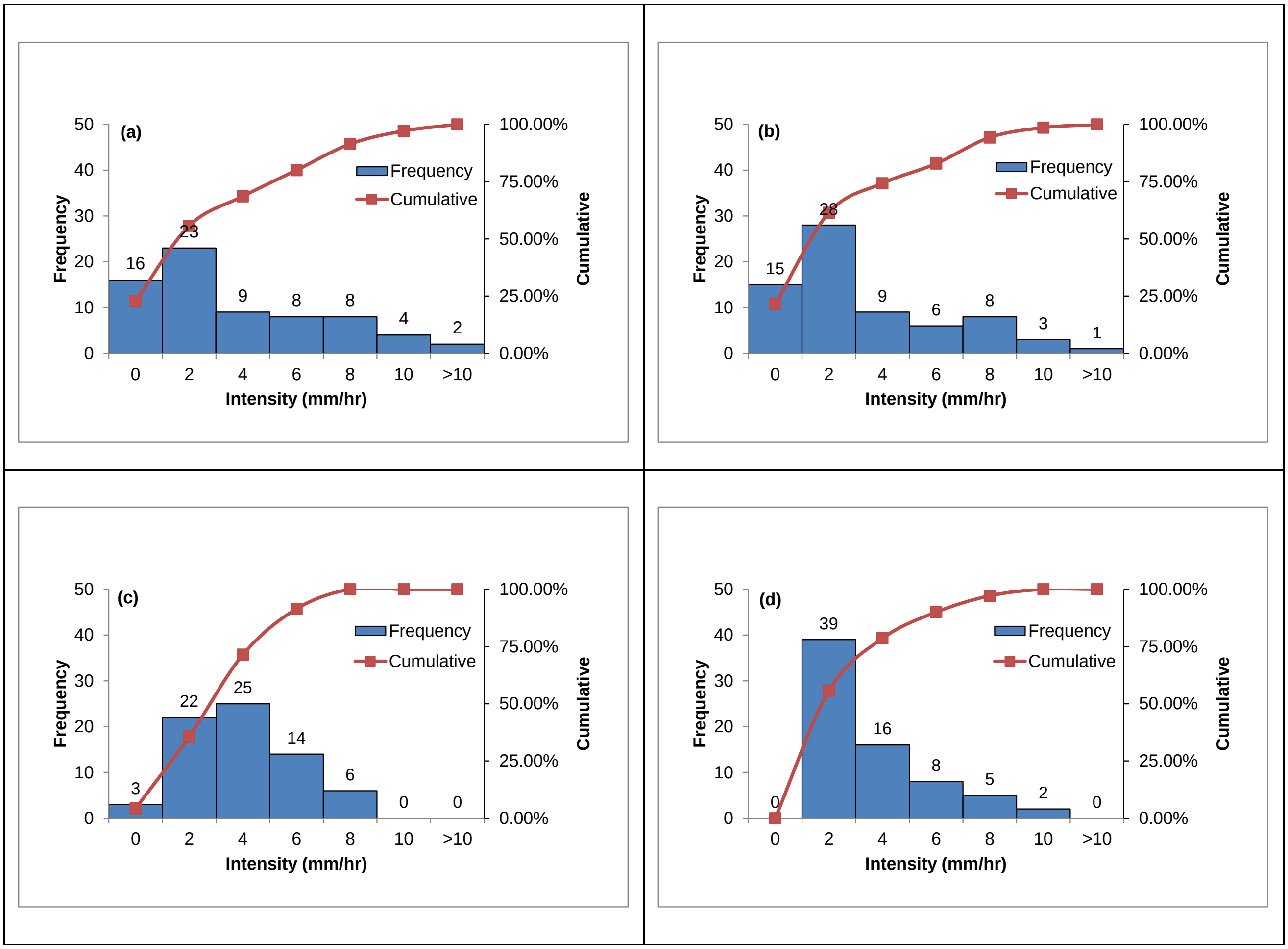

Figure 3: Histograms of rainfall intensity at 2-mm intervals: (a) rain gauge, (b) the TRMM, (c) the PERSIANN, and (d) ERA-I.

data, or for downscaling are all influenced by the probability distribution as all of these procedures must be able to reproduce the observed statistical properties. It is now known that techniques developed for mid-latitude precipitation may not be applicable to the topics (Rebora et al., 2006). Therefore an essential step in the interpretation and use of rainfall in tropical latitudes is identification of the most appropriate probability distribution. These data show a clear

TRMM, PERSIANN, and ERA-I estimates at 2-mm/hr intervals. All of the products follow an approximate exponential distribution, with the lower intensity events being far more frequent than higher intensity. The ERA-I data, which was most Gaussian in distribution, shows a monotonic decrease. All of the products, except the PERSIANN, show a mode of 2 mm/hr; the mode of the PERSIANN occurred at 4 mm/hr. Figure 4 also shows that the TRMM and ERA-I overestimate the occurrence of the lowest-intensity (2 mm/hr) events. However, the frequency of the rain gauge and PERSIANN estimate are essentially the same. There is no significant difference between the number of 4-mm/hr occurrences detected by the rain gauge and the TRMM but they are overestimated by both the PERSIANN and ERA-I. The 6-mm/hr occurrences are over-estimated by PERSIANN and underestimated by the TRMM. The estimates show similar skill at 8 and 10 mm/hr. These data show that heavy rainfall events (10-50 mm/hr) were very rare, occurring only twice with the rain gauge and once with the TRMM.

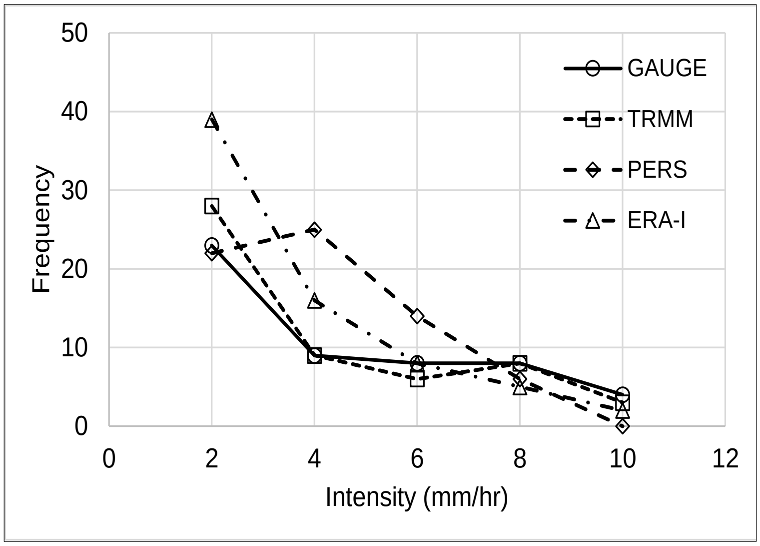

Figure 4: Comparison of gauge data with TRMM, PERSIANN, and ERA-I estimates at 2-mm/hr intervals.

Performance of Estimates

The estimates were assessed using categorical statistics according to Table 1 and the results are summarized in Table 2. ERA-I scored the most hits (56%) during light rainfall, with the TRMM the second most (53%) and the PERSIANN the lowest (39%). Based on threat scores, ERA-I was the more skilled in detecting light rain (TS=0.81) and extreme events (ETS=0.57), than TRMM (TS=0.76) and PERSIAN (TS=0.64). However, the ERA bias was highest (1.18) suggesting a tendency to over-forecast light rain relative to TRMM (1.15) and PERSIANN (0.73). The low PERSIANN bias is consistent with Figure 3, which showed identical occurrences for PERSIANN and rain gauges. The TRMM estimates showed the lowest error (RMSE=0.69) and PERSIANN the highest (0.76) so although TRMM tends to over-forecast the number of occurrences relative to PERSIANN the estimated intensities are more accurate.

Table 2: Average hits (with percent of total), bias, threat score (TS), and equitable treat score (ETS) for light (0 – 2.5 mm/hr), moderate (2.5 – 10 mm/hr) and heavy (10 -50 mm/hr) rainfall TRMM, PERSIAN and ERA-I data.

Rainfall (mm/hr)	TRMM					PERSIANN					ERA-I				
	Hits	Bias	RMSE	TS	ETS	Hits	Bias	RMSE	TS	ETS	Hits	Bias	RMSE	TS	ETS
0 - 2.5	37 (52.9)	1.15	0.69	0.76	0.47	27 (38.6)	0.73	0.76	0.64	0.41	39 (55.7)	1.18	0.72	0.81	0.57
2.5 - 10	19 (27.1)	0.82	2.66	0.59	0.43	26 (37.1)	1.46	2.52	0.60	0.36	21 (30.0)	0.82	2.86	0.70	0.57
10 - 50	0 (0.0)	-	-	0.00	-0.01	0 (0.0)	-	-	0.00	0.00	0 (0.0)	-	-	0.00	0.00

During moderate rainfall, PERSIANN scored the most hits (37%) and TRMM the lowest (27%) but ERA-I show the highest threat score (TS=0.70). The higher PERSIANN hits in the 2.5 – 10 mm/hr range is due to its over-forecasting in the 4 – 6 mm/hr range (Figure 3). This is reflected in the higher bias (1.46). Both ERA-I and TRMM showed the same amount of bias (0.82). The lowest RMSE was for PERSIANN (2.52 mm/hr) when compared to ERA-I (2.86 mm/hr) and TRMM (2.66 mm/hr). These results suggest that PERSIANN estimates of intensity would be the most accurate in this range. A skilled estimator would have RMSE = 0 so a value of 2.52 is quite large. Table 2 shows that none of the products detected rainfall in the heavy (10 – 50 mm/hr) category. Although TRMM reported a rate of 11.12 mm/hr, it was not recorded as a hit but as a false alarm. Therefore, for all the products H=0 and TS=0. As a result, BIAS and RMSE were incalculable.

To further characterize the relationship between the estimates and observations, a simple regression was performed (Scott, 2011). The correlation between two normal random variables is considered statistically significant if the sample correlation coefficient, r, is greater than $r^* = 2/\sqrt{N}$. Correlation of the estimates for all TCs against the entire rain gauge network across all the islands (N=143, r^*=0.167) resulted in r values of 0.518 (TRMM), 0.571 (PERSIANN), and 0.343 (ERA-I). When compared to r^*, all of the correlations are statically significant ($\alpha<0.05$). However, the high bias for TRMM (0.55), PERSIANN (0.78) and ERA-I(-1.48) as well as high RMSE of 4.24 mm/hr, 3.35 mm/hr, and 3.64 mm/hr for TRMM, PERSIANN, and ERA-I, respectively limits use of the relationship for correction or prediction.

In an attempt to improve the accuracy of the estimates, data from individual storms were correlated and compared to the critical values. Although the correlations improved, the bias and RMSE scores were still quite high (Scott, 2011). Figure 5 shows cross plots and correlations of estimates and observations during Tomas regressed for Martinique only. The network mean r's were 0.62 for TRMM (Figure 4a), 0.62 for PERSIANN (Figure 4b), and 0.67 for ERA-I (Figure 4c), which when compared to r^*=0.24, are all statistically significant (α = 0.05). Visual inspection shows that even though the correlation is significant, product accuracy is limited. This is supported by the high RMSE and non-zero bias. Values of RMSE were 2.69 mm/hr for TRMM, 2.48 mm/hr for PERSIANN, and 2.40 m/hr for ERA-I. Values of the bias were -0.56 for TRMM, -0.12 for PERSIANN, and -0.58 for ERA-I, suggesting that all of the products underestimated intensity.

When precipitation estimates were regressed on observations at individual gauges in Martinique during Tomas, the correlations were dramatically improved with r ranging from 0.45 to 0.83. With the r^* = 0.53, many of the correlations were significant but the best are shown in Figures 4d-f. The most predictive relationship for the TRMM (r = 0.79) was derived from the Vauclin gauge (Figure 4d). The gauge at Morne Rouge/Saint-Pierre provided the best relationship for the PERSIANN with r = 0.78 (Figure 4e) and the ERA-I with r = 0.83 (Figure 4f). For the TRMM the bias increased from -0.56 to 0.59, going from under-prediction to over-prediction at the local scale. For the PERSIANN, bias increased from -0.12 to 0.99, from a slight under-prediction to over-prediction, whereas for ERA-I, it increased from -0.58 to -0.41, an improvement but still an under-prediction.

In terms of the accuracy of the predictions, the RMSE for TRMM decreased from 2.69 mm/hr to 1.86 mm/hr; for the PERSIANN it remained essentially unchanged (2.45 mm/hr) whereas it decreased from 2.40 mm/hr to 1.51 mm/hr for ERA-I. Overall, ERA-I appears to be the most accurate with the lowest RMSE and smallest bias. These findings suggest that a generalized calibration for the region may have significant error but the error can be reduced through site-specific calibrations.

Conclusions

Knowledge of the amount and distribution of rainfall resulting from TCs is essential for quantifying and managing disaster risk. Owing to the sparse rainfall monitoring network in the Caribbean and infrequent data collection, satellite and reanalysis products offer potential to reduce uncertainty in rainfall estimates. However, routine use of products like TRMM, PERSIANN and ERA-I, especially for damage and loss models, require calibration against ground-based rain gauge data.

Rain gauge intensities were almost 2 times those estimated by the precipitation products and the spread about the mean was higher. Differences in rates resulted in accumulation ratios (products : gauge) ranging from 0.49 (TRMM) to 0.7 (PERSIANN) for the same period. The higher mean intensity and variance in the rain gauge data are attributed to the higher temporal resolution. These discrepancies are likely to increase the uncertainty in timing the initiation and duration of rainfall-induced hazards and ultimately loss projections for insurance products.

Probability distributions of intensity, which are essential for downscaling and the estimation of missing values, were also calculated. All of the datasets were non-Gaussian and followed an approximate exponential distribution, with the low-intensity events being far more frequent than high-intensity events. Based on threat scores, ERA-I was the more skilled in detecting light rain and extreme events, than TRMM and PERSIAN. However, the ERA bias was highest, suggesting a tendency to over-forecast light rain. The PERSIANN was most accurate in matching frequency of light rain detected by the rain gauges. Although TRMM tends to over-forecast the frequency of light rain relative to PERSIANN the estimated intensities are more accurate with the lowest RMSE. The PERSIANN over-forecasted moderate rainfall but it was the most accurate in matching the intensities. Heavy rainfall events were very rare, and when they did occur, were classified as false alarms. The accuracy of a rainfall estimate comprised of contributions from the different products, weighted according to intensity, may be worth evaluating.

Regression of precipitation estimates on rain-gauge data for the entire network for all the TCs show small, but statistically significant, correlations. However, the high bias and RMSE for the precipitation products limit use of the relationship for correction or prediction. Analysis of individual storms improved the correlations but the bias and RMSE scores remained high. Network mean correlations coefficients were calculated for Tomas over Martinique only. Although the correlations were statistically significant, model accuracy remained low with high RSME and non-zero bias.

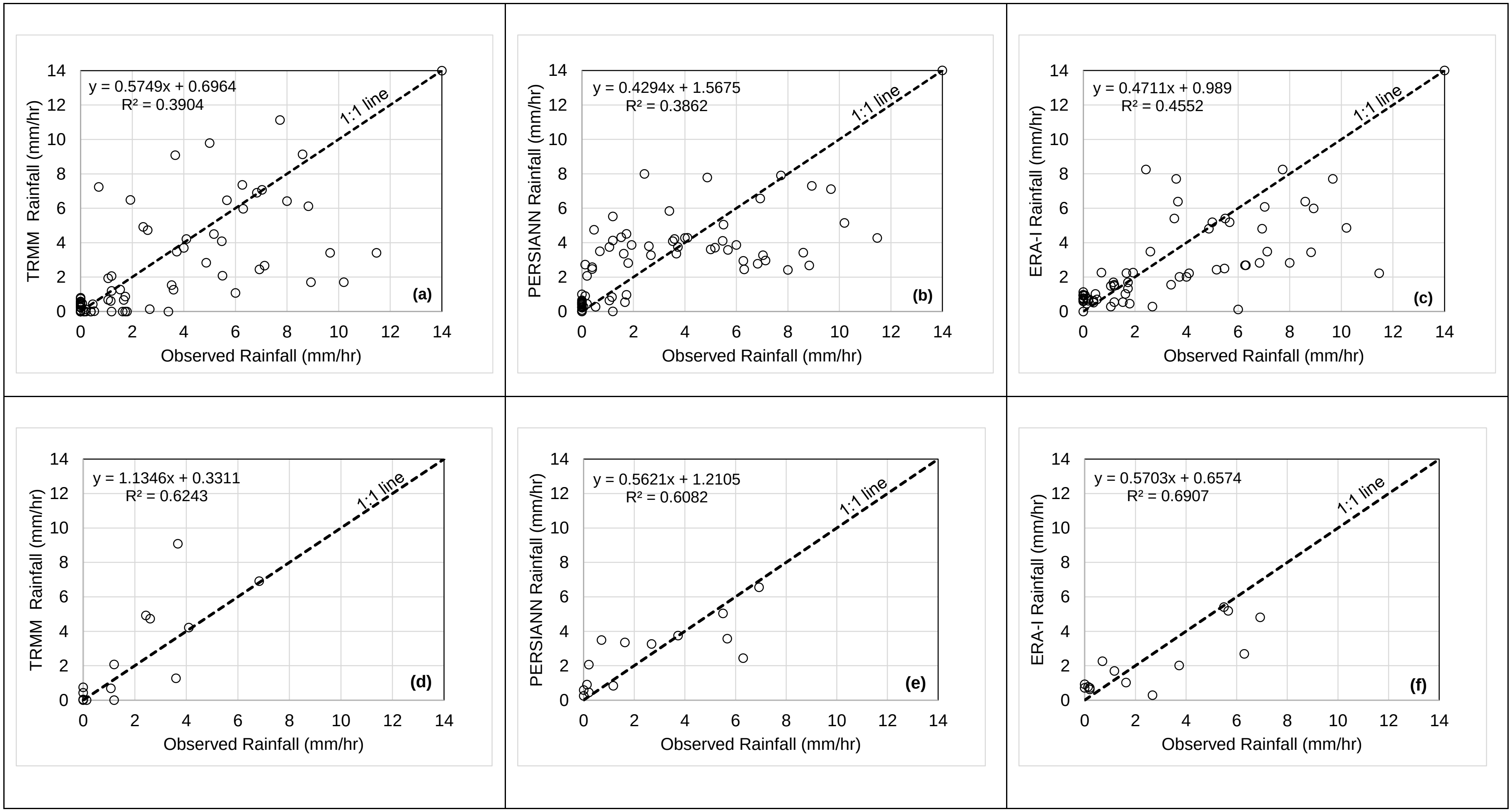

Figure 5: Scatter plots of rainfall intensity from the three products and rain-gauge (a) network average TRMM, (b) network PERSIANN, (c) network ERA-I, (d) TRMM at Vauclin, (e) PERSIANN at Morne Rouge & Saint-Pierre, and (f) ERA-I at Morne Rouge/Saint-Pierre. The diagonal line on each plot represents the 1:1 line expected for a skilled predictor.

In the final analysis, regression of precipitation estimates on observations at individual gauges in Martinique during Tomas produced the best correlations with statistically significant *r* values ranging from 0.45 to 0.83. The relationships with the lowest RMSE, least bias, and best correlations for TRMM (r = 0.79) came from the Vauclin gauge. The gauge at Morne Rouge/Saint-Pierre gave the best results for PERSIANN (r = 0.78) and ERA-I (r = 0.83). Overall, the ERA-I appears to be the most accurate with the lowest RMSE and smallest bias. While it appears that a generalized calibration for a region may have some error, the error can be reduced through site-specific calibrations.

Rainfall intensities estimated from satellite and reanalysis products can resolve tropical precipitation systems, such as TCs reasonably well. However, there are some fundamental issues that must be recognized when comparing the data sets. It is not unusual for satellite products to record rain over a region when it is not raining at the gauge. Similarly, it often rains at the gauge between satellite overpasses. It is essential that the data be properly averaged in space and time. Work is on-going to evaluate the effect of averaging periods on the accuracy of the relationships. The sensitivity of relationships between satellite products and rain gauges to the local climatology and other factors has also been reported in the literature for other latitudes. The inter-island as well as intra-island dependence of the relationships raises questions on the validity of generalized calibration for TCs. Undoubtedly a general equation introduces additional uncertainty in the rainfall rates used to force models for predicting the initiation and duration of rainfall-induced hazards estimating damage and loss. These findings suggest that site-specific relationships may be more accurate.

Acknowledgements

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Capacity Assessment Earthquake Unit, Mona, Jamaica

By Anna Tucker

This paper was prepared for course 'Hazard Vulnerability & Risk Analysis' in the MSc programme in Natural Resource Management - Disaster Risk Management at the University of the West Indies.

Introduction

The core function of the Earthquake Unit (EQU) at the University of the West Indies (UWI) is research. As a unit of UWI, it is funded by the Government of Jamaica (GOJ) and is part of the Department of Geology and Geography in the Faculty of Pure and Applied Sciences.

The EQU is the sole agency responsible for the monitoring of earthquakes and seismic hazard assessment in Jamaica. The EQU operates The Jamaica Seismograph Network (JSN), which is a network of 12 analog short-period seismograph stations installed across the island. The data from the JSN stations are transmitted to the Central Recording Station (CRS) at UWI-Mona in real time using radio signals. The data are recorded on computers running data acquisition and processing software.

The EQU also operates the Jamaica Strong Motion Network which is a network of eight accelerographs installed across the island to record ground shaking for larger earthquakes.

These instruments operate in a standby mode and start recording when triggered by an earthquake. They provide very important data to be used in seismic hazard assessment, which studies the response of sites to ground shaking and provide parameters to be used in constructing or retrofitting important structures. Another area of operation is the GPS network which has over 36 points across the island to monitor fault movement or strain accumulation over time.

This report presents the findings from the Capacity Assessment of the Earthquake Unit conducted in April 2013. An analysis of the findings is provided and a capacity strengthening strategy and monitoring and evaluation strategy proposed to improve the functions of the EQU in assessing earthquake risk at the national and local level.

Objectives

- To identify current internal capacity of the Earthquake Unit
- To assess sustainability factors that influence the existing capacity of the Unit
- To assess key stakeholder partnerships and external capacity of the EQU
- To assess capacity to plan, manage and implement projects and programmes
- To propose a capacity strengthening strategy to promote business continuity
- To propose a monitoring and evaluation strategy that can serve to enhance implementation of the functions of the Unit

Methodology

Screening

Desktop research was conducted to acquire background information on the Earthquake Unit. This included the following:

- Reviewed articles written about the work being done by the Earthquake Unit
- Reviewed Earthquake Unit Annual Report
- Reviewed collaborative work being done with the ODPEM and other agency stakeholders
- Field Reconnaissance – visited the office of the Earthquake Unit. Made observations of the existing working environment (spatial layout, staff relations, storage of equipment and documentation of records):
  - Conducted interviews with technical staff regarding data collection, analyses and interrelationships within the Unit
  - Conducted interview with the Unit Head
  - Took photographs of spatial layout, equipment and electronic and hardcopy data

Scoping/Capacity Assessment

Situation Analysis - A SWOT Analysis was conducted to identify the capacity issues and an assessment made of the sustainability factors that directly or indirectly influence the capacity of the Earthquake Unit. The variables of capacity were categorized and assessed as follows:

i. Identity and Governance - assessment of the Unit's structure, work ethics (including culture), reputation, mission and values
ii. Strategy and Planning - assessment of how the Unit achieves its broad long-term objectives and the effectiveness of its Strategic and Operational Plans. The overall planning process and monitoring mechanisms were also assessed.
iii. Management and Reporting - assessment of how the Unit supports the continuous improvement of individuals and organizations to provide better goods and services for the stakeholders they serve; assessment of change management, risk management, staff relationships and reporting mechanisms used as performance indicators
iv. Human Resource Management – assessment of existing human resource capacity including recruitment and staffing procedures and compensation packages; assessment of the performance management system to determine its contribution to staff development
v. Financial and Material Resource Management – assessment of current procedures for the management of finances to uncover implications to the functions of the Unit; assessment of inventory, documentation and recording procedures
vi. Stakeholder Partnerships – assessment of the strength of existing partnerships, including that with policy makers, donors, media relations and community stakeholders
vii. Knowledge Transfer Mechanisms - assessment of the internal mechanisms for transferring technical data and knowledge; assessment to ascertain evidence of knowledge transfer among agency partners and community stakeholders

viii. Services and Results - assessment of the effectiveness and the extent of outreach initiatives; the Unit has done extensive research and analyses into earthquake hazards and the use of seismic risk technologies

Development of a Capacity Strengthening Strategy

The findings of the capacity assessment were used to inform the development of a capacity strengthening strategy that will enhance the existing capacity and sustainability of the Earthquake Unit.

Limitations of the Capacity Assessment

Time Constraints - The time allotted to complete the assignment was insufficient to facilitate a more detailed capacity assessment of the Earthquake Unit.

Interviews - Only staff that were present on site were interviewed.

Field Observation - Field observation was restricted to the offices of the Earthquake Unit. Due to time constraints no site assessment was done for any of the reported installations set up islandwide.

Situational Analyses

SWOT Analysis

Table 1 presents a capacity SWOT (strengths – weaknesses – opportunities – threats) analysis of the Earthquake Unit.

Table 1: Capacity SWOT Analysis of the Earthquake Unit

STRENGTHS	WEAKNESSES
1. Earthquake hazard identification 2. Regional and international collaboration with academic institutions 3. Geospatial data outputs of earthquake hazards (hazard maps, seismic risk maps, impacts etc.) 4. Active community outreach programmes (sensitization of schools and agencies) 5. Strong media relations (information disseminated nationally on earthquake hazards) 6. Staff highly respectful of Unit head and each other 7. Unit budget guaranteed through the University of the West Indies 8. Projects developed and implemented through local, regional and international stakeholder partnerships	1. Low staff complement and inadequate work space 2. Limited technical staff 3. Bottleneck of leadership and management 4. Limited knowledge transfer internally 5. Limited integration of technical skills from agency stakeholders 6. Insufficient budget to effectively implement operational plan 7. Inadequate supply of equipment for data collection and research 8. Poor management of volunteers
OPPORTUNITIES	**THREATS**
1. Growth of internal technical staff 2. Provision of advanced technology and equipment for earthquake hazard assessments 3. Increased media coverage 4. Relocation of Office on or off campus 5. Development of a Volunteer programme 6. Increased funding from donor agencies 7. Expansion of earthquake public awareness and education initiatives 8. Revenue generation	1. Heavy reliance on donor funding for data collection, equipment and hazard assessments 2. Lack of succession planning and internal knowledge transfer 3. Inadequate technical staff 4. Staff turnover rate (technical staff) 5. Limited supply and access to advance equipment

Sustainability Factors

Sustainability of the Earthquake Unit is at the foundation of its mission towards facilitating increased resilience against earthquake hazards. The Unit's functions will only be sustained through ongoing decisions that not only meet the short-term needs but ensure the long-term viability of the initiatives. Table 2 illustrates sustainability factors that were holistically assessed within the Unit. These factors are assessed in detail throughout the report.

Table 2: Sustainability Factors identified for the Earthquake Unit

Component	Capacity Area	Level of Achievement
Organizational Sustainability	The Unit has internal capacity, networks and reputation to attract and retain qualified staff and adheres to its mission and values	WEAK
	The Unit monitors the effectiveness of its stakeholder partnerships and documents this through reports	WEAK
Financial and Resource Sustainability	The Unit's cash flow is consistently adequate to meet operational requirements	POOR
	The Unit manages its assets to control costs and as appropriate to maximize income for financial viability	WEAK
	The Unit generates credible proposals and concepts and demonstrates the cost effectiveness of its projects	WEAK
	The Unit is supported by a diversified resource base without overdependence on a single funding source	POOR
	The Unit has strategies and mechanisms consistent with its core programme areas which are efficient for generating sustainable income for a portion of its operating costs	POOR
	The Unit's fundraising raising process is integrated with a financial administration system and is monitored and adjusted on an ongoing basis	WEAK
	The Unit has adequate qualified staff and systems in place to access and manage and account for resources from diversified donor sources	POOR
Programme Sustainability	Programmes are focused and prioritized to reflect the values and strategic direction of the Unit and advance the mission	WEAK
	The Unit is a recognized leader in its core programme areas	GOOD
	Programmes are designed and implemented equitably, inclusive of those who are most vulnerable and in need of access to programme services	WEAK
	Programmes address gender and other equity concerns	POOR
	Increasing numbers of people benefit from initiatives undertaken by the Unit	GOOD
Political Sustainability	The Unit is able to readily mobilize internal and external support for its programmes	WEAK
	The Unit has fostered a loyalty among stakeholders and has a respected public image	GOOD
	The Unit has capacity to produce local evidence of the needs and effectiveness of its programmes and to communicate these to Government, donors, private stakeholders and the general public	WEAK

Identity and Governance

The initial step in assessing the Unit's current capacity involved gaining an appreciation of the organization's mission and values. Key aspects of the mission of the Earthquake Unit indicate that it seeks to:

- Understand earthquake processes
- Advise the society about earthquake hazards
- Encourage earthquake awareness
- Apply mitigation strategies to development

Table 3: Functions of the Earthquake Unit

BROAD FUNCTIONS OF THE UNIT	MISSION COMPONENT
Seismic Hazard Mapping - Collection of seismic microzonation data, assessment of slope deformation due to earthquake induced landslides, vulnerability assessments	Understand earthquake processes
Sensitization of Stakeholders-Presentations conducted to community and agency stakeholders. The Education Sector has also benefited from islandwide earthquake awareness conducted in schools	Advise the society about earthquake hazards
Initiatives through the Global Earthquake Model-Provision of standardized data that can be used to develop regional and international models for seismic assessments.	Encourage earthquake awareness
Maintenance of the Jamaica Seismograph Network (JSN) - Operation of a network of twelve (12) analog short period seismograph stations installed across the island and two (2) broadband seismographs. ***Establishment of the Jamaica Strong Network*** - installation and maintenance of accelerographs across the island used to record ground shaking for earthquakes and structural response. ***Development and Implementation of Projects*** - Collaboration with international partners for enhanced research and provision of equipment and expertise.	Apply mitigation strategies to development

It was found that the daily functions of the Unit do reflect the mission. It was evident however, through research, that the Unit's efforts towards these initiatives were not readily known to most communities, despite the Unit itself being a household name.

Consultation with a sample of the Unit's staff indicated a general understanding of the organization's mission, vision and values. The staff also expressed that the daily functions of the Unit are in accordance with the mission and vision (Table 3). These include but are not limited to those shown in Table 3.

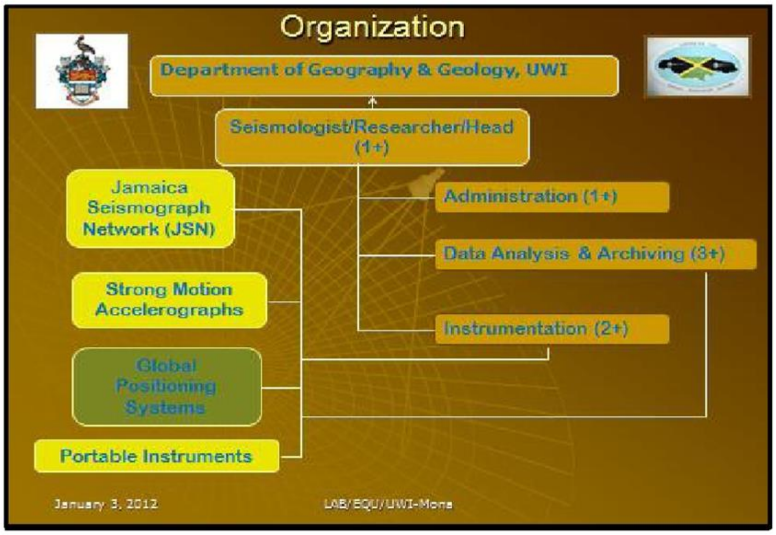
The Earthquake Unit is an arm of UWI, which is funded by the Government of Jamaica. The internal governance structure of the Earthquake Unit was not clear or visible through the existing organizational structure depicted in Figure 1.

The structure emphasizes data management but fails to depict the job positions that are associated with each function. It is therefore difficult to ascertain the interconnectivity among staff roles and responsibilities.

Site observation and staff consultation revealed that most of the staff operate in 'silos' where job functions though interdependent are not shared or understood among each other. It was found that one individual is assigned to each position within the Unit. This increases staff risk and potential staff turnover and restricts knowledge transfer and succession planning. It was also unclear whether team building activities are conducted among the staff, outside of scheduled staff meetings.

Strategy and Planning

The capacity assessment indicated that the long-term viability of the Earthquake Unit is directly linked to the achievement of the Unit's objectives in the Strategic and Operational Plans. Discussions with the head



of the Unit revealed that components of the Operational Plan are integrated into staff job descriptions and are used to inform decision making and prioritize activities to be undertaken annually.

Queries about staff performance indicated that staff members are assessed in accordance with the Operational Plan. It was mentioned however that discretion is exercised in the absence of adequate human, material and financial resources for staff to effectively carry out job functions.

This "discretion" somewhat implies that the existing Strategic and Operational Plans are unrealistic or highly optimistic. The Unit's budget is aligned with the Operational Plan. All budgetary allotments are then approved or rejected by the Accounts Executive of the University. It was also found that there is a heavy reliance on donor funding to support execution of duties outlined in the Strategic and Operational Plans.

Currently, the internal capacity of the staff is limited. Many of the activities listed in the Operational Plan hinge on the availability and access to external technical assistance from partner agencies. Also, it was unclear whether a monitoring system exists for quantifying and qualifying the achievement of plan objectives.

Management and Reporting

The management structure of the Unit is bottom heavy with all staff reporting to the Unit head instead of an established hierarchy. The head of Unit indicated that greater focus is placed on the management of data processes and systems than on human resources. As mentioned previously, there is currently no spatial representation of the reporting hierarchy of the staff. Middle managers such as the Engineer/Network Manager and the GIS Specialist do not have subordinates or support staff. For all technical posts there is only one of each. This is indicative of budgetary constraints for recruitment and lack of sufficient equipment and technologies to facilitate execution of duties.

The reporting mechanism within the Unit is somewhat informal, where the Unit head receives internal communication directly from each staff member. This communication is conducted mainly via email and face to face dialogue. The Administrator facilitates and directs most of the external communication. However, the Unit head is responsible for signing off on technical information to be disseminated externally.

The management style of the Unit head was found to be flexible. It was observed that staff are allowed to independently develop activities for executing tasks outlined in the Operational Plan. Most of the information shared among staff is done electronically via email.

There are manual files (books, articles, journals, reports) in storage but they are used primarily for retrieval of data archives to aid student research. There is evidence of sound data management within the Unit. Documents are systematically stored and archived for use by internal and external stakeholders who retrieve and access information from the Unit's library. However, the current storage capacity of the Unit is inadequate and the existing library area is small and serves also as a thoroughfare to offices and cubicles (Plates 1 and 2).

Plates 1 & 2: Earthquake Unit Library

The Unit has recently upgraded to electronic management of seismic data collection and analyses through the establishment of the electronic National Data Centre (NDC) located within the Unit that is linked to the wider International Data Centre (IDC) located in Vienna.

This data are processed and analyzed jointly with earthquake data from the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) International Monitoring System. During daily operations, internal data security is managed by the IT/Electronic Technologist, who quality controls data retrieval and analysis procedures and report findings to the IDC. The head of the Earthquake Unit is also knowledgeable about the workings of the electronic NDC but has limited capacity to support maintenance of the equipment. Plates 3 and 4 depict the NDC within the Unit.

Plates 3 & 4: Infrastructure of the Electronic Data Centre

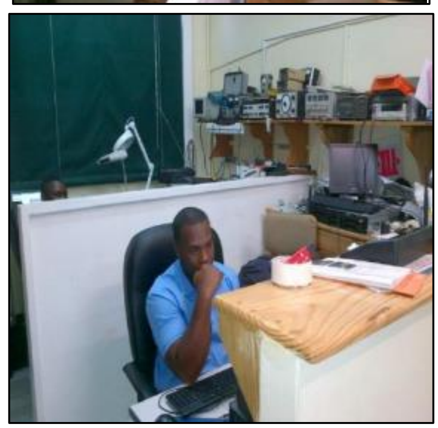
Human Resource Management

Human resource management applies a coherent approach to the management of an organization's most valuable assets: the people who individually and collectively contribute to the achievement of the organization's objectives. The Unit is led by a qualified and experienced individual (Research Fellow) and the existing staff are fully committed to the organization's mission toward earthquake disaster risk reduction. Nonetheless, there is a need for additional technical staff to absorb the demand for advanced research of earthquake hazards.

The performance management system, namely the PMAS, allows staff to monitor their individual progress through their work plans. It was found that, while staff are assessed using this system, in the absence of adequate resources it is impractical to expect optimum delivery of duties. During interviews, some staff members expressed that there is little or no room for upward mobility within the Unit. It was explained that opportunities exist only for parallel movement into technical areas. This would require cross training as each technical area has only one individual assigned. The budgetary constraints also make it difficult for staff to upgrade their competencies through extensive training. To date, most of the training conducted has been funded through projects and is focused on training that complements the work of the funding source.

Recruitment and compensation procedures of the Unit have been weak due primarily to financial constraints. The Unit head explained that it has been difficult to attract and retain qualified and technical staff. The existing recruitment process, though transparent, is highly competitive as there are little or no registered vacancies within the Unit. The Human Resources Department of UWI spearheads the recruitment process for the Earthquake Unit in consultation with the Unit head/Research Fellow. It was expressed that there is need for greater use of volunteers who can be trained in technical competencies for earthquake hazard identification and analyses and made to operate on a part time basis within the Unit.

The spatial layout of the Earthquake Unit is not conducive to an expansion of its technical base and administrative functions. The current staff are restricted by small cubicles, bordered by heavy equipment mounted on shelves above the cubicle walls that poses a threat from earthquakes (Plates 5 and 6).



Plates 5 and 6: Earthquake equipment poorly stored above occupied cubicle stations.

Site observations revealed a high risk of the Unit's working space from fire hazards. A kitchenette occupies a small room to the rear of the building and has poor ventilation (Plate 7). The library located left of the entrance/ exit with its high paper content poses a threat to staff as the paper could act as fuel in the event of a fire and potentially block the entrance/exit (Plate 8).

Plate 7: Small kitchenette located in rear of building

Plate 8: Section of the library

Throughout the office, there was evidence of loose electrical wiring located in close proximity to work stations and areas where entanglement of limbs is highly probable (Plates 9 and 10). The staff operate in unsafe conditions on a daily basis. Continued observations during site visits indicate an ad hoc assembly of wires to accommodate the increased use of electronic equipment within the Unit. This increases the vulnerability of staff to electrocution and electrical fires.

Plates 9 and 10: Loose electrical wiring at work stations

One positive aspect expressed by staff members regarding the small working space is the ease of rapport and dialogue between staff. They indicated that being close, phone calls are seldom. However, further queries revealed that the open floor discussions are seldom work related.

Staff interviewed expressed that they are driven by their passion for earthquake hazard identification and analyses, more so than the incentive of their salary packages. It was found that the current staff turnover rate negatively affects operations of the Unit, as an individual that leaves is usually the sole person conducting a particular job function. This is evidence of a lack of succession planning and knowledge transfer.

Financial and Material Resource Management

All finances and budgets for the Unit are routed through the accounting services of UWI. As such the Unit cannot make independent decisions for the use of funds, including project funds. Evidence suggests that the Unit complies with all internal and external audit requirements regarding the expenditure of funds and is given some flexibility. The Unit head also indicated that regular internal and external financial reports are made available to UWI and/or donors. However, the Unit has limited control over the approval of funds for specific deliverables.

An annual budget is drafted by the Unit head and forms part of the justification for components of the Operational Plan. The allocation of funds, however, requires approval from UWI and thereby restricts the priority areas of the Unit, such as the purchasing and installation of equipment for data collection and research. It is perceived that the Earthquake Unit and its related functions are low on the priority list for the University, as the budget has recently been cut from J$36 million to J$25 million per annum. According to the Brief Synopsis on the Earthquake Unit (2012), the current budgetary allotment for the period 2012 - 2013 was approved at J$29.54 million. This is lower than the required minimum of J$36 million.

Stakeholder Partnerships

The Earthquake Unit is renowned among government stakeholders, non-governmental organizations (NGOs) and international donors. The work done by the Unit has fostered stakeholder relationships that have influenced the progression of research into earthquake hazards. The integrity of the staff and the credibility of the Unit's work over time have served to strengthen stakeholder partnerships locally, regionally and internationally. Some partnerships have been formalized through the signing of Memoranda of Understanding (MOUs) for the provision of equipment to conduct research and of funding for projects. Some of the key stakeholders of the Earthquake Unit are UWI and other local universities, regional and international universities, the IDC, ODPEM, Norman Manley International Airport (NMIA), TransJamaica Highway, Ministry of Local Government, Kingston and St. Andrew Corporation (KSAC), Land Information Council of Jamaica, Ministry of Labour and Social Security, Caribbean Disaster Emergency Management Agency (CDEMA) and international donors.

Information about current or planned services and activities of the Unit are not consistently made available to its stakeholders on a timely basis. Inadequate data sharing has been observed as a constraint between the Unit and its external stakeholders. The Unit head indicated that the recently modified electronic NDC houses earthquake data in a manner that is not compatible with most electronic databases found within other agencies. As such the Unit has to process the earthquake data and format them for use by local and external partners. It was also made known that the Earthquake Unit is unable to process all datasets stored within the NDC and as such relies on the assistance of the NDC in processing and interpreting some datasets.

Data created and processed within the Earthquake Unit are usually packaged in a manner that meets the demands of target audiences. Community stakeholders, however, are at a disadvantage as the Unit has failed in most instances to simplify technical jargon and images for the benefit of local communities. Earthquake information is disseminated to schools (mainly secondary and tertiary level). It is important to note that the information about earthquake hazards is sometimes lost in the complexity of the message. The assessment revealed that the Unit quantifies the number of presentations held in schools and the number of children reached but no evaluation is made of the effectiveness of the outreach initiative.

Donor agencies are highly influential to the success of the Earthquake Unit. Given the limited financial and technical resources available, the dependence on donor funding has gradually increased. The provision of financial resources is usually project driven which may or may not align with the priorities set by the Unit in a given year. The assessment revealed that the current capacity of the Unit to leverage resources from donors both locally and abroad is weak and is reflected in the inability to conduct some activities. However, it is important to note that the Unit is highly recognized for the work being done and respected by government and international partners. This admiration has secured resources towards earthquake research and analyses. It was also found that most of the equipment purchased and installed throughout the island has been sourced from international partners through the implementation of projects.

Despite the infrequent occurrence of high magnitude earthquakes, the Earthquake Unit is a household name, though commonly associated with the Office of Disaster Preparedness and Emergency Management (ODPEM). It was observed that most information on earthquake-related information is communicated via a top down approach, where information from the Unit is fed to the public via the media. The communication channels used mainly by the Unit are technical presentations that offer little room for feedback and interaction to promote a better understanding of technical information. The Unit head indicated the existence of a Public Relations Officer, but to date, the Scientific Officer has been operating in this capacity. This poses limitations to the use of appropriate reporting mechanisms and language for addressing target audiences, especially the general public.

Knowledge Transfer Mechanisms

The capacity assessment revealed limited knowledge transfer occurring within the Earthquake Unit organizational structure and among staff. Though each job function is co-dependent on another, the staff seem to operate in silos where they produce work without an appreciation or full understanding of its contribution to the whole. End products are developed, packaged and issued to relevant stakeholders. The end products are usually interpreted by the IT head, who is most knowledge in the use of geotechnical processes for earthquake hazard risk identification. Interviews conducted with some staff during field observations, indicate a high vulnerability to knowledge gaps among technical staff. Each person is a specialist in his or her field and there was no perceived mechanism for cross-training or internal awareness building.

The head of the Unit stated that there is a weakness in the use and analysis of GPS data. Data are collected using the device, but data retrieval and analysis are limited to the GIS Specialist who sometimes requires external assistance. This results in delays of tasks that are highly dependent on the use of GPS data.

Internally, most of the knowledge and expertise about earthquake hazards and geotechnical data analyses reside with the

Unit head. The Seismic Analyst and GIS Specialist work closely with the Unit head (Research Fellow) and seemingly benefit from continuous knowledge transfer and capacity training. This benefit is however limited to technical staff.

Information sharing is also fostered through staff meetings and project briefings. Members of staff revealed that cross training[1] is not conducted despite staff's limited technical capacity. Staff meetings and project briefings that can broaden awareness are also infrequent. It was found that the Unit head is often out on travelling duties and there is usually no assigned individual to assume responsibility of the Unit during his absence. The knowledge and experience of the current head of Unit is invaluable, yet to date there is no evidence of planning for succession to his leadership.

Currently, public awareness campaigns in schools and agencies promote awareness more than education in the actual use of equipment and tools for data collection and analysis. Also, the Unit has failed to maximize its use of volunteers. The staff revealed that volunteers assist in data collection and analyses but there is no strategy for increasing the volunteer pool. To date, volunteers consist only of those who exercise their own initiative and express an interest. This limits the consistency and availability of volunteers with technical competencies. It is also evident that there is a greater need for integration of technical staff from partner agencies in conducting research and data collection led by the Earthquake Unit.

Government agencies such as the ODPEM and National Works Agency (NWA) actively use earthquake data generated by the Earthquake Unit. Private organizations such as NMIA also use data generated from the Unit to inform decisions. The NMIA has also purchased and installed equipment for enhancing data collection and reducing risk at the airport. It is important to note that most agency stakeholders do not have the capacity to collect, interpret and analyze earthquake data. It was expressed that limited training is provided by the Earthquake Unit to partner agencies to increase technical capacity in this area. This has proven to be challenging as the already short-staffed Unit is spread thin in trying to meet the demands and needs of its agency stakeholders.

Services and Results

The Earthquake Unit has made a mark on the local, regional and international communities regarding earthquake hazard identification, analysis and awareness. With its current staff complement of seven, the Unit is responsible for the establishment of seismic networks for data collection and has developed several outputs since its inception including hazard maps, fault maps, and digital earthquake models to name a few. Table 4 outlines some of the services offered by the Unit and the results achieved.

[1] Training that exposes staff to job functions outside the scope of their existing technical competencies and allow for better understanding and appreciation of overall roles and functions of the Unit.

Table 4: Services Offered by the Earthquake Unit

Service	Activity	Target/ Coverage	Results to Date
Hazard Mapping	Chirp Sonar Survey - mapping of fault offset, tsunami evidence, submarine landslides	Islandwide	Survey completed for Kingston Harbour
	Mapping and dating of earthquake induced landslides	Islandwide	Several slopes in the Kingston Metropolitan Area (KMA) mapped to inform urban planning
	Development of seismic hazard maps	Islandwide	Partnership with Seismic Research Centre, UWI, St. Augustine through the Disaster Risk Reduction Centre UWI Mona (World Bank-funded project)
	Seismic microzonation data collection	Islandwide	Seismic microzonation data has been collected across 168 points across the KMA
Earthquake Modelling	Supplying the Global Earthquake Model with regional earthquake modelling data	Caribbean	Ongoing
	Seismic Hazard Assessment of Historical and Critical Infrastructure	Islandwide	Ongoing
Academic Research	Collaboration with institutions through access to equipment and other expertise for earthquake research and facilitation of research conducted by students	Academic Institutions	Collaboration with 9 universities 6 student research theses currently underway
Seismic Networks	Jamaica Strong Motion Network	Islandwide	8 accelerographs installed
		Islandwide	12 seismographs
	GPS network	Islandwide	36 GPS stations installed
Data Manage-ment	Operation and maintenance of the National Data Centre	Stakeholders (Agencies & Institutions)	Ongoing
Earthquake Alerting System	Installation of automated alerting system for rapid response	Islandwide	Pilot being developed
Data Transfer	Exchange of earthquake data and network metadata with international and regional networks	Regional & International	Ongoing
Training	Training of volunteers in data collection and use of technical equipment	General Public	Ongoing
	Training of technical staff and project teams	Agency stakeholders	Ongoing
Stakeholder Sensitization and Awareness Building	Conducting presentations on earthquake safety and risk	Schools (mainly secondary and tertiary level), agencies (Govt. and NGOs)	Presentations conducted in schools across the island at the primary, secondary and tertiary levels
	Conducting sensitization meetings	Communities	To be determined
Research Papers and Publications	Provision of earthquake hazard and risk analyses to local and internal journals, media publications	Islandwide, regional and international	Technical report recently developed for Annotto Bay, St. Mary Recent publication (2012) in the Geophysical International Journal

Proposed Capacity Strengthening Strategy

Table 5: Proposed Capacity Strengthening Strategy for the Earthquake Unit

Sustainability Factor	Capacity Issue	Recommendation	Actions to be Taken	Responsibility/ Support	Resources Required	Expected Time-frame	Estimated Cost
Identity & Governance	Public perception of the Earthquake Unit	Inform the public about the role of the Unit	Conduct sensitization meetings among stakeholders	EQU/UWI/ International Donors	Funding	Ongoing	To be determined
Identity & Governance	Public perception of the Earthquake Unit	Inform the public about the role of the Unit	Increase engagement with public media	EQU/ Partner agencies	Research evidence on earthquake hazards	Ongoing	N/A
Identity & Governance	Public perception of the Earthquake Unit	Promote the diversity of the Unit	Create tangible outputs that can support works of multiple sectors	EQU/Local and international universities/ International donors	Geospatial Software (GIS) -Instruments and equipment for data collection and analyses	Ongoing	To be determined
Identity & Governance	Lack of internal awareness of correlating job functions	Promote knowledge transfer of technical skills among staff	Conduct task swapping among staff as part of capacity building	EQU (Unit head to authorize)	Internal workplans -Project activities for designation	Quarterly	N/A
Identity & Governance	Lack of internal awareness of correlating job functions	Promote knowledge transfer of technical skills among staff	Staff members to present reports during staff meetings to build awareness	All staff	Monthly Reports	Monthly	N/A
Identity & Governance	Lack of internal awareness of correlating job functions	Develop initiatives that strengthen staff relations	Adopt best practices from similar organizations (regional and international)	EQU (All staff)	Research evidence from similar organizations	Ongoing	N/A
Identity & Governance	Lack of internal awareness of correlating job functions	Develop initiatives that strengthen staff relations	Acquire feedback on suitable initiatives	EQU (Head of Unit)	Evaluation templates	Ongoing	N/A
Identity & Governance	Limitations to achieving the Unit's mandate	Incrementally execute tasks that directly address the mandate	Prioritize functions in accordance with mission on an annual basis	EQU	Strategic and Operational Plans -Proposed budget allotment -Annual Reports	Ongoing	N/A
Strategy and Planning	Completion of Annual Operational Plan	Draft Priority Action Plan	Consult with staff on proposed priority actions	EQU (led by Unit head) -UWI to review		Quarterly	N/A
Strategy and Planning	Completion of Annual Operational Plan	Draft Priority Action Plan	Outline activities to be conducted	EQU	-Strategic and Operational Plans -Annual Reports	Quarterly	N/A
Management and Reportin	Unstructured Reporting Mechanism	Establish Communication Flow and Network	Develop an internal 'Call Out' Tree	EQU	Staff contact information	Ongoing	N/A
Management and Reportin	Unstructured Reporting Mechanism	Establish Communication Flow and Network	Maintain an electronic inventory of updated contact information to agency partners	EQU (Administrator/IT Coordinator)	Software for database creation	Ongoing	To be determined

Sustainability Factor	Capacity Issue	Recommendation	Actions to be Taken	Responsibility/ Support	Resources Required	Expected Time-frame	Estimated Cost
		Develop an external Notification Flow chart	Acquire up-to-date emergency contact information for emergency responders	EQU/ODPEM/UWI	Contact information	First quarter	N/A
	Weak Management Structure	Revise existing organizational structure	Create a threshold for subordinates to report to middle management	Consultant/UWI/EQU	Funding	First quarter	N/A
Human Resource Management	Low staff complement	Increase technical staff complement in the short term	Recruit additional staff	EQU (Unit head to authorize)	Increased budget for salary packages	Ongoing	To be determined
		Develop strategy for incorporating external technical Support	Consult with partnering agencies to develop strategy for accessing external technical resources	EQU/UWI/NWA/ MGD/ODPEM/Trans-Jamaica/ KSAC	Signed MOUs	To be determined	To be determined
	Technical Competency of Staff	Enhance and upgrade technical competences of internal staff	Conduct training needs assessment	Consultant/ EQU	Funding (consultant)	First quarter	To be determined
			Provide cross training internally (understudy technical posts cyclically)	EQU	Temporary staff (part-time students/ recent graduates/ volunteers)	Ongoing	To be determined
	No Successor for the Unit Head	Implement succession planning	Provide leadership training for middle managers	EQU/ UWI/ODPEM/ International donors	-Training Material -Qualified Instructors	Ongoing	To be determined
	Poor Coordinator of Volunteers	Establish volunteer programme	Conduct Volunteer Needs Assessment (include technical requirements)	Consultant/ EQU	-Funding -Existing record of volunteer support	First Quarter	N/A
			Create and maintain electronic volunteer database	EQU (Administrator, IT/Electronic Technologist)/ ODPEM	-Software for database creation -Listing of volunteers	Ongoing	To be determined
		Activate the use of volunteers	Develop action plans linked to Operational Plan	-EQU/Technical agencies (Govt./ NGOs)	Volunteers	Ongoing	N/A
	Inadequate Work Space (size & layout)	Relocation of Office/ Relocation of some divisions within the Unit	Identify suitable building on or off campus	UWI (Engineer)/ EQU/ Consultant	Proposed spatial plan design	To be determined	To be determined
			Transition relocation of staff	EQU/UWI	-Haulers -Additional office furniture -Advanced technology and equipment	To be determined	To be determined
	Staff Performance	Enhance staff performance	Establish incentive package for high performers	EQU/UWI/ International donors	Funding	Ongoing	To be determined
			Conduct annual PMAS	EQU (Unit Head)/ UWI (Human Resources)	PMAS Template	Annually	N/A

Sustainability Factor	Capacity Issue	Recommendation	Actions to be Taken	Responsibility/ Support	Resources Required	Expected Time-frame	Estimated Cost
Financial and Material Resource Management	Inadequacy of Budget	Develop justification for budget increase	Itemize required budgetary allotment for priority actions	EQU/ Donor agencies (local & international)	-Annual Reports -Proposed projects -Operational Plan	First quarter	N/A
		Seek alternative funding to support Unit activities and projects	Develop a funding model	Consultant/ EQU/ International donors	-Funding (consultant) -Sample Models for adoption or adaption	First quarter	To be determined
			Develop comprehensive strategy for revenue generation	Consultant/EQU	-Record of current income generation	First quarter	N/A
	Finances controlled by UWI	Establish Accounts Department within the Earthquake Unit	Develop and submit proposal to Board members and Advisory Committee for approval	EQU	N/A	First quarter	N/A
			Recruit accounting staff	UWI/ Earthquake Unit	Budget for salaries	First quarter	To be determined
	Inadequate storage and maintenance of material resources	Designate secure storage for equipment	Create and maintain electronic inventory of all equipment stored internally	Earthquake Unit (IT/Electronic Technologist)	Software for database creation	Ongoing	To be determined
			Provision of suitable internal/external storage area for equipment	EQU/ UWI	Storage facility/area	First Quarter	To be determined
		Maintain equipment and material resources	Schedule regular maintenance of all equipment (including hardware & software)	EQU/UWI/ Consultant	Duty Roster Funding	Monthly/ Quarterly	To be determined
			Establish and maintain equipment & Infrastructure connectivity	Consultant/ Agency partners/ EQU	Funding	Ongoing	To be determined
	Storage capacity of internal servers to accommodate large and complex earthquake data	Store electronic data on offshore servers	Identify stakeholder partners to store data	EQU	Inland and offshore Servers	First Quarter	To be determined
Stakeholder Partnerships	Failure to complete data collection points (seismic-microzonation projects) in specified project timeline	Prioritize locations for data collection points	Identify suitable locations to install data collection points	EQU	GPS equipment	Ongoing	To be determined
			Partner with stakeholders to assess and monitor data collection points	EQU	Volunteers	Ongoing	N/A
		Conduct regular monitoring of the data collection points	Establish stakeholder partnerships to assess data collection points and analyze data	EQU/Partner agencies	Monitoring and evaluation instruments	Ongoing	To be determined
	Availability of data and equipment to	Source financial and human resources to	Engage research students as volunteers for data collection	Earthquake Unit	Volunteers (students)	Ongoing	N/A

Sustainability Factor	Capacity Issue	Recommendation	Actions to be Taken	Responsibility/ Support	Resources Required	Expected Time-frame	Estimated Cost
	support research	support earthquake research					
	Sustained funding of projects and installations	Source funding from donor agencies and NGOs	Write proposals to donor agencies and NGOs	EQU/ Consultant	Funding	Ongoing	To be determined
	Current capacity of critical facilities (mainly health care facilities)	Conduct data collection of structural stability of critical facilities	Install accelerometers	EQU/ Partners	Funding Equipment	Ongoing	To be determined
	Cost and ownership of monitoring and maintenance of all installations	Seek sponsorship for the purchasing of equipment	Target donors for funding	EQU	Funding	Ongoing	To be determined
	Community Engagement	Strengthen local community presence and involvement	Establish community-based earthquake risk reduction projects	EQU/ODPEM	Funding	Ongoing	To be determined
			Conduct regular community sensitization meetings and workshops	EQU/ODPEM/ SDC/Partners	Training material - Qualified Instructors - Venue and refreshments	Ongoing	To be determined
			Attend Parish Disaster Committee Meetings	EQU/ODPEM (Regional Coordinators)/ Parish Councils	Meeting Agenda	Quarterly	N/A
			Conduct presentations to agency stakeholders (national & local level)	EQU	-Qualified Presenters	Ongoing	To be determined
			Invite communities as part of volunteer programme to support the Unit	EQU/SDC/ ODPEM	Volunteers	Ongoing	N/A
	Partnerships with community groups	Establish partnerships with community-based organizations	Identify and engage existing CBOs	EQU/ODPEM/ SDC	Records of established CBOs	Ongoing	To be determined
	Heavy reliance on Donor Funding	Develop revenue generation system	Assess the current income generating activities being undertaken	EQU/ Consultant	N/A	First Quarter	To be determined
			Develop an electronic database for tracking revenue	Consultant	Funding	First Quarter	To be determined
Knowledge	Weak Internal Knowledge Transfer	Establish mechanism for internal knowledge sharing	Technical staff to understudy each other's tasks	EQU	N/A	Ongoing	N/A

Sustainability Factor	Capacity Issue	Recommendation	Actions to be Taken	Responsibility/ Support	Resources Required	Expected Time-frame	Estimated Cost
		Conduct knowledge transfer to technical agency partners	Conduct training workshops and indulge agency partners in data collection processes	EQU/Donor agencies	Funding	Ongoing	To be determined
	Insufficient Training at Community Level	Develop community training programmes	Partner with agency stakeholders to develop training programmes	EQU/ODPEM/SDC	Funding	Ongoing	To be determined
Service & Results	Effectiveness of Outreach Programmes	Develop programmes for expanding the work of the Unit	Partner with donor for provision of equipment	EQU	Funding	Ongoing	To be determined
	Quantity of Research	Increase staff complement and volunteers	Partner with agency stakeholders to conduct research	EQU	Funding	Ongoing	To be determined
	Availability and use of advanced technology	Acquire upgraded equipment and tools	Seek donor funding to purchase equipment and tools	EQU/Donor agencies	Funding	Ongoing	To be determined
	Media Relations	Increase media coverage of works being done by the Unit	Invite the media to workshops, trainings and project based field activities	EQU	Funding	Ongoing	To be determined

Monitoring and Evaluation

The following Action Plan Monitoring Report template can be used to monitor and evaluate the progress of the Earthquake Unit following each capacity assessment.

Action Plan Review Date:

Participants:

Introduction
(No more than one page, describing the event, its objectives and main results.)

Progress made since last organizational capacity assessment
(Describe progress made against the last action plan in one or more of the nine capacity areas based on the indicators. List obstacles faced and new opportunities.)

Areas that need work
(Describe the needs identified and summarize the discussion points by the capacity areas discussed. Describe new actions to be conducted to move implementation of action plan forward.)

Follow-up
(Describe steps to further institutionalize regular organizational capacity assessment, to integrate action plan into annual implementation plan supporting the strategic plan.)

Attachments
(A copy of last action plan, revised action plan, etc.)

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Climate Smart Agriculture: Can It Be Achieved?

By Mahendra Saywack

This paper was submitted as the main assessment for the course 'Climate Resilient Development' in the MSc Climate Change and Development programme at the University of Sussex.

Introduction

The changing climate is hitting smallholder farmers hard. It is doing so especially on the African continent which is regularly pronounced as most vulnerable to the impacts of climate change (Newsham and Thomas, 2009; IFAD, 2012). Climate change brings droughts and floods, pests and diseases; it means poorer crops, less food and lower incomes. It also accelerates land degradation. With two-thirds of the world's poor dependent upon the land, their livelihoods are at risk (World Bank, 2011a). The impact of climate change also has repercussions that extend far beyond the supply of food. Agriculture accounts for twenty-nine percent of the Gross Domestic Product (GDP) in developing countries, and it provides employment for sixty-five percent of their populations (Smith, 2011). Hence, the economic health of these countries is closely linked to the fortunes, or misfortunes, of farming communities.

Climate-Smart Agriculture (CSA) is agriculture that sustainably increases productivity and resilience, reduces or removes GHGs and enhances achievement of national food security and development goals (FAO, 2010).

The aforementioned impacts can all be attributed in part to the rapid increase in greenhouse gas (GHG) emissions from human activities. With developing countries experiencing unprecedented levels of economic growth, there is mounting concern that future growth in energy demand and the accompanying increase in GHG emissions will be dominated by these countries (OECD, 2002; IEA, 2012). As such, reducing these emissions has become one of the cornerstones of efforts to move towards a future international climate change agreement under the United Nations Framework Convention for Climate Change (UNFCCC). However, imposing caps to developing countries' GHG emissions has met strong resistance in past negotiations, as caps are perceived as a constraint to future growth prospects (Linares and Pueyo, 2012). Hence, there has been a race to find new, unconventional initiatives to avert the rising emissions.

In recognition that agriculture is not only a victim and villain (Hedger, 2011), but also a potential solution in relation to climate change, one possibility that has surfaced in the international arena is that of sequestering carbon dioxide into soils using an approach known as 'Climate-Smart Agriculture' (CSA). First coined by the Food and Agriculture Organization (FAO), CSA is defined as "agriculture that sustainably increases productivity and resilience, reduces or removes GHGs and enhances achievement of national food security and development goals" (FAO, 2010). In other words, CSA strategies are those that achieve so-called 'triple wins' of adaptation, mitigation and development (Naess, 2011). Despite the growing momentum and support for this integrated approach that aims to bridge agricultural adaptation to, and mitigation of, climate change, policy actions have been slow to materialize at the global level as many countries continue to greet this initiative with strong resistance (Asaduzzaman, et al., 2012).

It is against this backdrop that this paper seeks to examine whether CSA can be achieved in practice. To inform this discussion, this paper engages with the growing body of literature on CSA to dissect the underlying issues which have led to modest progress in its adoption. In particular, this paper focuses heavily, though not exclusively, on empirical evidence from sub-Saharan African countries. The rationale for doing so inherently relates to the limited availability of applicable literature on this topic, which happens to be concentrated within that region.

Alongside this introduction, this paper also sets out to highlight the proponents' perspectives in relation to the climate-smart vision. As such, this section examines how agriculture may be considered both a problem and a solution to climate change. The latter is demonstrated with the use of concrete examples emerging from a suite of developing countries claiming to represent local successes of the approach.

The remainder of this paper directs its attention to the emerging critiques that oppose the CSA approach. While this section essentially synthesizes the broader challenges and insights noted by critics, emphasis is placed on assessing whether the adoption of 'no-till agriculture', (one of the main conservation-agriculture (CA) practices actively promoted under CSA), is capable of generating the 'triple-win' in reality.

Finally, based on the balance of evidence gathered, this paper culminates in determining not only the extent to which CSA can be achieved in practice, but also, whether the proposed interventions, and the main actors driving the agenda, have in their own vested interests the needs of smallholder farmers.

Agriculture: A Problem and a Solution?

According to Hedger (2011), agriculture is both a victim and villain in relation to climate change. The sector represents a victim based upon estimates indicating that climate change is likely to reduce agricultural productivity, production stability and incomes in some areas that already experience high levels of food insecurity e.g. South Asia and sub-Saharan Africa (Branca, et al., 2012). On the other hand, agriculture is also considered a villain in that the sector is a key source of GHG emissions: it is the largest source of global emissions for nitrous oxide, as well as carbon emissions from land use change. Overall, agriculture directly accounts for 14 percent of global GHG emissions, or approximately 30 percent when considering land-use change (IFAD, 2011, 2012; World Bank, 2011b). It is within this context that FAO (2010) suggests that agriculture in developing countries must therefore undergo a significant transformation in order to meet the related challenges of achieving food security and responding to climate change. Despite its significant contribution and vulnerability to climate change, agriculture may still play a critical role in the search for a global solution. In fact, as indicated by

Gattinger, et al. (2011), there is considerable potential for soil carbon storage which can be realized in most developing countries where 74 percent of all agricultural emissions originate.

It is on this premise that the unifying concept of climate-smart agriculture emerged with the hope of integrating the issues of food security, poverty, climate change and environmental sustainability. As suggested by the World Bank (2011c), CSA includes proven practical techniques including: agroforestry, crop rotation, mulching, conservation agriculture, intercropping, integrated crop-livestock management, improved grazing and improved water management, each of which may contribute towards achieving a triple-win for food security, adaptation and mitigation.

Moreover, a number of concrete examples have demonstrated that CSA is already at work in many parts of the world. For instance, in Niger, agroforestry techniques applied on five million hectares have benefited over 1.25 million households, increased grain yields by an extra half-million tons and sequestered carbon (World Bank, 2011c). Likewise, in Zambia, CA has enabled many farmers to double their maize yields as well as adapt to climate change as the organic matter afforded by this technique protects the soil from high temperatures thus reducing water needs of crops by as much as 30 percent (World Bank, 2011c; Smith, 2011). Additionally, in Kenya, the first agriculture soil carbon sequestration pilot project (Kenya Agricultural Carbon Project - KACP) is presently underway. This project, implemented by the World Bank, currently engages with 60,000 Kenyan farmers, and is geared towards mitigating climate change, supporting adaptation and increasing food security through various land management interventions (Suppan and Sharma, 2011). This project is estimated to generate storage of a total of 1.2 million metric tons of carbon dioxide by the end of its 20-year lifecycle (Braimoh, 2013; World Bank, 2011c).

Climate Smart Agriculture: Trojan Horse or Triple Win?

While on the surface the approach of CSA appears to resonate well with the demands of farmers and civil society organisations (as evident from the examples cited), linking agricultural production and climate resilience objectives with carbon sequestration objectives has been met with great skepticism, concern and even outright opposition at the global level. To this end, a number of critics have argued that the climate-smart vision is fraught with a multitude of problems.

The Many Faces of Climate-Smart Agriculture

The most pressing concerns relate to the economic viability of climate-smart practices. In general, the design and implementation of land management interventions require large financial investments and the World Bank has proposed that this should come from carbon markets (Sivakumaran, 2012). While soil carbon sequestration is currently excluded under the Clean Development Mechanism (CDM), critics have expressed fear that the potential expansion of carbon markets to accommodate this could spell disaster for smallholder farmers. In particular, they question the viability of carbon markets and more importantly, whether its payments to farmers would be more than symbolic (Naess, 2011).

Using the Kenyan Agricultural Carbon Project as a reference point, Maryknoll (2012) emphasized that the promised rate of return for smallholder farmers under this model is miniscule. It is important to note that, while the pilot project in question estimates to earn US$2.5 million from carbon credits, high start-up and transaction costs will absorb a significant share of the expected revenues (Suppan and Sharma, 2011). With 60,000 Kenyan farmers participating in this pilot project over a 20-year lifecycle, the project is only estimated to receive an average of US$22.83, or about US$1 per farmer per year;

assuming stable carbon prices of US$4/$tCO_2$ (Pearce, 2011; Maryknoll, 2012; Sivakumaran, 2012). In light of such negligible financial returns, this paper therefore questions the practicality in replicating this approach elsewhere. To this end, Sivakumaran (2012) has noted that the World Bank's case studies used to demonstrate the success of CSA all received a large amount of financing which would not be provided for similar projects adopting CSA. In the absence of the World Bank's financial support, Sivakumaran posits that this model is simply not replicable for other African countries. This has therefore led ActionAid et al. (2011) to conclude that such projects are either financially unviable, or would require public finance to sustain.

However, resorting to public finance to meet initial investments has raised yet another crucial concern among critics. As such, many have argued that CSA is politically unjust, as it shifts the responsibility of mitigation onto developing countries, and in particular, smallholder farmers (Maryknoll, 2012). Further, some also believe that the shared vision of CSA is biased towards mitigation efforts, which is in danger of diverting developed countries' attention away from their adaptation funding commitments. As cogently pointed out by Anderson (2011) and TWN (2012), CSA could potentially undermine farmers' rights, adaptation strategies and adaptation finance.

The concerns and doubts surrounding CSA interventions are indeed far-reaching. As such, another concern raised by critics relates to the common misconception that CSA practices, inclusive of conservation agriculture, are agro-ecological. As indicated by both TWN (2012) and Zundel (2012), CSA is certainly not agro-ecological, since it undermines the fundamental strength and social benefit derived from agro-ecology: agro-ecology does not need to be combined with other approaches that use fossil fuel-based chemicals, hence, it reduces farmers' dependency on external inputs. Added to which, its profits tend to be decentralised. However, as argued by critics, CSA approaches are closely linked to the actors who promote fertilisers, pesticides and industrial agriculture. In other words, the adoption of CSA interventions can lead to a lock in and dependency upon these external resources. To this end, Thibodeau (2011) purports that CSA practices are therefore being disguised and packaged as an agro-ecological image, in order to facilitate the consolidation of profits by agro-corporations.

Furthermore, as CSA proponents continue to claim that CA is the panacea for the problems of poor agricultural productivity and soil degradation (Giller, et al., 2009), a growing body of scientific evidence equally contradicts these claims. In particular, critics have persistently challenged the notion of no-till agriculture as a CA practice, and more specifically, whether it is capable of delivering a 'triple win' in reality. As the term implies, no-tillage or zero-tillage, is a soil cultivation system in which seeds are deposited directly into untilled soil (Gattinger, et al., 2011). From an adaptation standpoint, the practice of no-till appears to resonate well with many critics who endorse its ability to reduce erosion, improve soil structure and enhance water retention. These properties they posit, can increase farm systems' resilience and improve the capacity of farmers to adapt to climate change (Branca, et al., 2011; Gattinger, et al., 2011). However, as a counter-argument to this, Cannon and Mueller-Mahn (2010) suggest that, since CSA approaches focus specifically on making farming more 'climate resilient', this can result in the system losing resilience in other ways. They further stress that CSA interventions can increase casual processes which put people at risk. In particular, both Giller, et al. (2009) and Zundel (2012) have indicated this to some extent, noting that no-tillage can create an extensive weed problem which increases farmers' dependency upon herbicides. Where such inputs are not accessible, no-tillage can also mean decreased labour-saving due to the requirements of weeding and as noted by Giller, et al., (2009), this can have adverse gender effects particularly on women who take up this additional role.

It is a common assumption among CSA advocates that the resultant soil properties associated with no-tillage should provide a basis for higher crop yields. However, as pointed out by Giller, et al. (2009) and Gattinger, et al. (2011), the introduction of no-tillage can generate no yield benefits or even yield reductions during its first few years. For example, six years of no-tillage with the application of herbicides produced only marginal improvements in the yields of wheat and lentils in Ethiopia (Erkossa et al., 2006 cited in Giller, et al., 2009). Similarly, as Figure 1 illustrates, maize yields also varied over the first five years of no-tillage in both Nigeria and Zimbabwe.

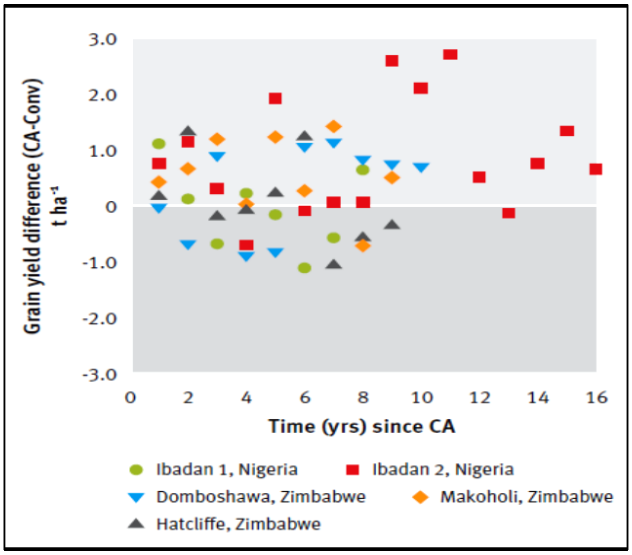

Figure 1: Maize grain yields (t/ha) under conservation agriculture practice compared with conventional tillage over time (Gattinger, et al., 2011)

According to Branca, et al. (2011), the full benefits in terms of more stable yields would only be realized in the long term, whereas investments are incurred up front.

Moreover, a parallel concern raised by Sivakumaran (2012) and Conway, et al. (2011) is that it is often assumed that if CSA can increase food production, this may lead to higher global food security. However, as they both pointed out, this relationship is not direct, especially since the majority of food producers also comprise the majority of food insecure. In other words, while increased productivity is necessary, it is not sufficient to ensure food security (*i.e.* access to affordable food). On this premise, this paper posits that CSA strategies need to find ways not just of steering people towards climate resilient pathways, important though this is, but they also have to contribute to addressing the underlying issue of food insecurity. As suggested by Sivakumaran (2012), CSA programmes must therefore provide mechanisms that guarantee higher incomes and improved livelihoods for the poorest in order to overcome the wider challenges of hunger and malnutrition rather than focusing solely on increasing food productivity.

Furthermore, in relation to the mitigation goal of CSA, issues surrounding soil carbon quantification have also emerged within the current discourse. Notably, for the mitigation benefits of CA techniques to be realized, this would depend on the level of accuracy involved in monitoring, reporting and verification (MRV) of soil carbon sequestration. However, as noted by several critics (Anderson, 2011; Paul, 2011), soil carbon measurements are highly complex and contested, especially since sequestration rates vary among soil types and depths and the fact that carbon storage can be easily reversed through farming practices e.g. ploughing (Branca, et al., 2011). As indicated by Suppan and Sharma (2011), the World Bank's pilot study in Kenya would depend upon computer-based models rather than actual soil sampling to deduce sequestration measurements. This they argue would not reflect an accurate representation of the soil conditions, as models are based on inherent assumptions/ limitations, and downscaling can further amplify errors. Given such complexities, this paper argues that the mitigation pillar of CSA remains stifled with technical uncertainties, which may therefore diminish its contribution and any assurance towards a 'triple-win'. In other words, without scientifically robust MRV, the mitigation goal remains highly questionable.

In addition to the difficulties noted with MRV, some critics have also questioned the outright sequestration capacity afforded by no-tillage. While CA advocates maintain that no-tillage combined with residue mulching reduces carbon emissions since the soil remains undisturbed, discouragingly, recent empirical evidence appears to refute this claim. In particular, Giller, et al. (2009) and Gattinger, et al. (2011) have highlighted that this notion is flawed since it is largely based on studies of carbon change restricted to the upper 10 cm of soil where soil organic matter (SOM) is likely to accumulate. Given the lack of soil mixing under no-tillage, these critics have argued that the CA benefits of overall increases in SOM may therefore be overestimated. To this end, it is worth noting that a recent meta-analysis of soil carbon storage under CA has revealed no carbon benefits, and even carbon deficits at depths below 20 cm, thus confirming the stratification of SOM in the top soil only (Giller, et al., 2009). On this premise, critics have determined that it is not conclusively proven whether reduced tillage leads to increased SOM content and enhanced soil fertility. Hence, the potential contribution to carbon sequestration and reduced emissions under no-tillage remains questionable.

The concerns regarding no-tillage extend far beyond its carbon sequestration capacity. In particular, since no-tillage currently comes packaged with monocultures, genetically modified (GM) crops and extensive herbicide usage, Naess and Newell (2012) have expressed fear that investments in this technique will be skewed away from the concerns of the poorest and towards large-scale agriculture. Moreover, the fact that the FAO has called for the inclusion of offsets from no-till agriculture (despite its uncertainties and inconclusive situation), reinforces this bias towards large-scale agriculture. As suggested by Ernsting, et al. (2009), the FAO's recommendation clearly reflects vested interests in GM crops and the biotech industry at large. While GM crops have not yet been formally proposed for offsetting, it is worth noting that large agri-businesses such as Monsanto already claim that their Roundup Ready GM crops should be eligible for carbon offsets. They argue that the application of their glyphosate herbicide on their herbicide-tolerant GM crops, reduces tillage for weeding and therefore reduces carbon emissions from the soil (Anderson, 2011).

Although offsets from soil sequestration are currently excluded from carbon markets, critics warn that future inclusion could potentially intensify the land grab epidemic already taking place in Africa (Anderson, 2011;Maryknoll, 2012; Sivakumaran, 2012; TWN; 2012). Such intensification may also lead to subsequent displacement of smallholder farmers who currently lack land tenure security, thus reinforcing their marginalization (Sivakumaran, 2012). Additionally, as cautioned by Pearce (2011), the continuous promotion of no-tillage may also facilitate a lock-in and increased dependency of marginalized farmers upon external inputs. Added to which, linking agriculture to carbon offset schemes may lead to farmers cultivating only what is incentivized rather than their traditional crops.

Adoption Does Not Guarantee a Triple-Win

Based on the critical insights presented in this paper, it is evident that the potential of no-tillage to guarantee a triple-win remains questionable and bounded by uncertainties. Moreover, this paper has recognised that CSA interventions in general are mainly driven by particular actors (donor agencies and NGOs), and while these proponents continue to advocate for the scaling-up and replication of best practices, this will with no doubt conform to the vested interests of multi-national corporations as opposed to smallholder farmers. Like the many opponents of CSA, this paper is inclined to agree that expanding carbon markets to include soil sequestration will result in soil being treated as a commodity, rather than a necessity for food security, thus leading to competing goals and evitable tradeoffs.

In light of the overwhelming concerns noted in this paper, the proponents of CSA have called for potential reforms to be made in order to foster widespread adoption of climate-smart practices. According to Naess (2011) and FAO (2011a,b), the uptake of CSA interventions would be contingent upon stronger political leadership, supportive and coherent government policies and strategies, land tenure arrangements that make investments worthwhile, as well as access to markets and inputs. Moreover, the provision of financial support for smallholder famers is also considered a crucial requirement during the transition towards CSA. In particular, FAO (2011a) has indicated that the introduction of credit programmes or subsidized programmes would be necessary to enable farmers to overcome one-off investment barriers. However, given that the returns to agriculture might be accrued only in the long term (as evident with no-tillage), some form of financing to support farmers during this transitory phase would also be necessary (FAO, 2012). To this end, the proponents have suggested a broad range of instruments to support farmers' income. Such activities include upfront payments for environmental services, the development of alternative income sources e.g. handicraft or the establishment of agricultural processing activities that can generate employment, and access to productive social safety nets. The latter as posited by FAO (2010), represents a form of social insurance for farmers and possible programmes include cash transfers, food distribution, seeds and tools distribution and conditional cash transfers.

Uptake of CSA interventions will be contingent upon:

- **stronger political leadership**
- **supportive and coherent government policies and strategies**
- **land tenure arrangements that make investments worthwhile**
- **access to markets and inputs**
- **provision of financial support for smallholder famers**

Although these recommendations and reforms are appealing, whether they will foster widespread adoption of CSA interventions still remains to be seen in practice. This is primarily because the current evidence of CSA adoption has been restricted to pilot studies driven by significant donor support. In addition, this paper also posits that the uptake of CSA practices would not guarantee the delivery of environmental and economic benefits for smallholder farmers. In other words, adoption of CSA interventions does not necessarily imply the achievement of the triple-win goals. This notion is inherently based on the premise that there are too many open questions and uncertainties concerning the impact of CA practices on crop yields and carbon sequestration. Given that the current body of scientific literature does not substantiate the high expectations of these practices, the present and future role of CSA interventions remains questionable.

Furthermore, while the proponents of CSA maintain that equipping smallholder farmers with the necessary building blocks may help to facilitate widespread adoption, this still does not dismiss the grievances that such an approach can essentially undermine farmers' interests and the very goals the vision sets out to achieve. After all, CSA continues to be touted and packaged as an agro-ecological image, but in reality, its principles are underpinned by industrial agricultural practices, a strategy that can potentially do more harm than good to smallholder farmers. Moreover, this paper strongly argues that the local successes portrayed by the donor community are far from being unbiased reference points in deciding whether CSA can actually exist beyond the project level let alone be independent of donor support. At the same time, it has been recognised that the proponents, in their call for potential reforms, have continued to overlook the more critical issues of social injustice imposed upon farmers in their responses to emerging criticisms, thus leaving more questions than answers within the CSA discourse.

To this end, this paper maintains that while the prospects of CSA are appealing, they remain contentious. It is for this reason that this paper opines that the bigger question smallholder farmers may now have to ask themselves is whether the uptake of CSA practices will foster the kind of transformation in farming systems and livelihoods that are in their own interests, or will it result in an increased dependency upon external inputs and reinforced perpetual poverty? Given that CSA is still within its infancy stage, the answer to whether it can be achieved in practice is one which remains largely indeterminate. Nevertheless, the balance of evidence offered in this paper has presented an illuminating glimpse of what a future with CSA might hold. From all indications, the climate-smart vision, as currently packaged, does not appear have in its interests the needs of smallholder African farmers, but rather, those of multi-national corporations.

Conclusion

This paper sought to examine whether the shared vision of climate-smart agriculture can be achieved in practice. In light of the ideas and arguments presented, this paper suggested that the achievement of the climate-smart vision is one that remains largely indeterminate.

This outlook was based on the premise that achievement of each of the triple-win goals, though appealing, was highly contentious. In particular, the findings clearly demonstrated that the current scientific evidence available did not substantiate the high expectations of CA practices such as no-tillage. In effect, there were too many open questions/ concerns, scientific uncertainties and inconclusiveness surrounding the triple-win goals of mitigation, adaptation and food productivity/ security. To this end, this paper suggests that there is a need for more robust evidence to be generated in order to improve the validity of the triple-win claims, especially those related to soil carbon quantification / sequestration capacity, and the influence of CA practices on crop yields.

Additionally, it should be noted that the overall conclusion made in this paper was not driven by the level of scientific uncertainty alone. In fact, the wider socioeconomic concerns of farmers' marginalization, weak viability of carbon markets, and speculative land grabbing also contributed to the skepticism in determining whether widespread adoption of CSA would actually benefit smallholder farmers. Unfortunately, based on the balance of evidence in this paper, the key actors leading the CSA agenda do not appear to have in their interests the needs of smallholder farmers, but rather, those of large multinational corporations. In this regard, it is doubtful that the climate-smart vision as currently packaged can lead to a transformation in farming systems and livelihoods without undermining the sovereignty of smallholder farmers.

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The impact of hydro-meteorological hazards on crop production among small-scale farmers in Crofts Hill, Clarendon

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This is a synopsis of the thesis submitted for the MSc Natural Resource Management - Disaster Risk Management degree at the University of the West Indies

Introduction

Jamaica is known for agriculture although traditional crops that were once exported such as sugar cane and banana (Burrell 2010), are no longer the most significant crops produced. Over the years, the sugar industry has been through a number of phases where sugar production has fluctuated.

During this time, Jamaica's small-scale farmers have been trying to adapt to the various challenges that exist within the agricultural sector. Small-scale farmers are usually defined by the area of land cultivated which is normally lower than five hectares. Small-scale farmers typically grow "cash crops" which are sold at local markets. These crops also act as a means of subsistence for the farmer and his or her family. Cash crops are short-term crops grown intensely over a short period of time.

During most extreme weather conditions, the operations of small-scale farmers are usually affected. As a result of these conditions, small-scale farmers are not able to maximize the benefits of their labour based on the amount of damage done. Other limitations that affect small-scale farmers include location, size of their farmland and an adequate market to consume the crops produced. These factors can affect small-scale farmers' economic stability and ability to cope under significant financial burdens and market competition.

In the past, farmers in Crofts Hill have suffered from several hydro-meteorological hazards such as hurricanes (major and minor), tropical depressions and storms, droughts and flooding in particular areas. These hazards affect the normal operation of small-scale farmers. However, the level of displacement is often determined or influenced by the magnitude and duration of the hazard event. When crops are damaged by hydro-meteorological hazards, the farmer's economic gain can either increase, decrease or be removed entirely.

This research seeks to focus on particular hazards namely floods, droughts and hurricanes/tropical storms that affect farmers' crop production in Crofts Hill, in the parish of Clarendon, Jamaica. The effects of these hazards can result in a 'trickle down' or cascading effects on persons who depend on the farming sector. The implications of these hazards are assessed and recommendations provided.

Research Objectives

The objectives of the study are as follows:

1. To understand the direct and indirect impacts experienced by small-scale farmers resulting from the frequent occurrence of hurricanes, floods and droughts.
2. To critically examine the impact of hydro-meteorological hazards on future crop production of small-scale farmers.

3. To assess the coping mechanisms of small-scale farmers to deal with hydro-meteorological hazards and present recommendations that can reduce the impact of such hazards.

Description of Study Area

Political and Geographical Location

The study area, Crofts Hill, is located in the north-eastern section of Clarendon and is close to the borders of St. Ann and St. Catherine. It is located on the western side of the Crofts Mountain and north of Pindars Valley.

Hydrology and Hydro-stratigraphy

The hydrology of Crofts Hill is influenced by the soil, geology and geomorphology of the area. It includes a few surface streams and sub-surface drainage channels which drain the immediate watershed. However, the volume of water in the surface channels normally fluctuates with the seasonal changes in rainfall pattern.

Geology and Geomorphology

Jamaica is made up of 70% limestone and Crofts Hill is no exception. The area is comprised mostly of limestone rocks from the Upper Cretaceous series. Features such as round hills, valleys, sink holes and steep-sided slopes are typical. Although slopes over 30^{o} are not recommended for farming, farmers in Crofts Hill still include these areas in crop production.

Climate

As a result of the geographic location and the topographic characteristics of Crofts Hill, climatic conditions are favourable for crop production. Seasonal rainfall is predominant within the area but rainfall patterns have been affected by the impacts of climate change. The seasonal rainfall is characterized by the bi-modal peaks with most of this precipitation occurring in the months of October, September and May each year. The overall 30-year mean for Crofts Hill was measured at 317mm (PIOJ 2005). This pattern does not deviate much from the precipitation pattern for the rest of Jamaica.

Soils

The predominant soil type in the study area is clay loam but pockets of loam soil can be found in other areas (Plate 1).

Plate 1: Cracks in the soil caused from the effects of extended dry conditions

Land Use and Economic Activities

The main economic activity in Crofts Hills is farming which is done by mostly small-scale farmers (Burrell 2010; Bailey 2003). The main crops produced in the study area are sugar cane, yam, cabbage, lettuce and sorrel. Cash crops produced in Crofts Hill mimic the seasonal rainfall/bimodal patterns while sugar and yam are normally produced throughout the year. Economic activities also come in the form of wholesale and retail shops which can be found along the road network. In terms of land use, farming accounts for a large majority of the land area. However, Burrell (2010) highlighted that agricultural lands have been losing out to the development of houses or left idle. This coincides with a general decrease in the farming population (Tauger 2011) and agricultural lands in Jamaica (STATIN 2011).

Methodology

Although both qualitative and quantitative research approaches are effective and can be used on their own (Thurmond 2001; Mitchell

1986), the researcher used both approaches to collect data for this study.

The quantitative approach used was the administration of questionnaires and secondary data, while case studies, focus group discussions and participant observation were the qualitative approaches used.

Understanding Hydro-meteorological Hazards and Agriculture

Overview of hydro-meteorological hazards and agriculture

Within the context of the Caribbean region, hydro-meteorological hazards have affected the agriculture sector significantly (Méheux et al. 2007; McGregor et al. 2009; Chen and Taylor 2002).

Developing countries, such as those of the Caribbean, have experienced situations where hydro-meteorological hazards have led to increased import bills and increased market prices, along with significant decreases in traditional and non-traditional crop production and export crops (FAO 2002; McGregor et al. 2009; Spence 2009; Campbell et al. 2010). In addition, Spence (2009, 1) explained that "the vulnerability of Jamaica's agricultural sector especially to hydro-meteorological hazards such as hurricanes, floods, drought, high magnitude rainfall and related hazards such as landslides is underscored".

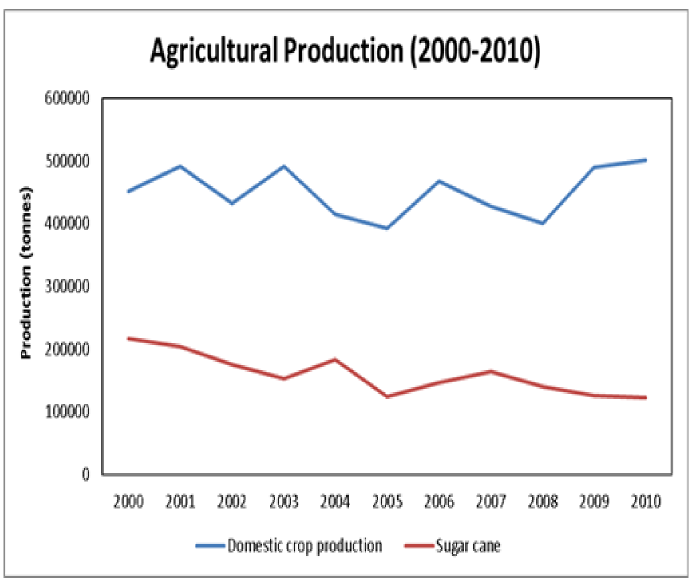

Figure 1: Jamaica: total domestic crop and sugar cane production 2000-2010. Source: RADA 2011 and SIA

Domestic crop production and sugar exports in Jamaica have been fluctuating over the last decade (Figure 1). Most of the decreases in production are recorded in years which were affected significantly by hydro-meteorological hazards such 2002, 2004, 2005, 2007 and 2008 (MOA 2003: 2005: 2010). The growth within the agricultural sector is restricted by the increase in the number of hydro-meteorological hazards that have affected Jamaica. As such, it is quite difficult for the agricultural sector to recover fully to the production levels it once had in the mid-1990s.

The decrease in the export of banana, which is a traditional crop, can be attributed to hurricanes (especially Hurricanes Gilbert and Ivan) which affected crop production significantly. In addition, sugar cane has faced its share of impacts from past events with the recent drought in 2009-2010 and Tropical Storm Nicole in 2010. It should be noted that while traditional crops are being affected, cash crops are more vulnerable to the impacts of these hydro-meteorological hazards (McGregor et al. 2009; Spence 2009; Campbell et al. 2010). McGregor et al. (2009) and others also state that cash crops normally take a shorter time to grow and require more resources for growth. In support, Campbell et al. (2010) argue that this is due to the fact that cash crops require more irrigation, fertilizers and more labour from farmers. However, all these processes can be affected significantly by hydro-meteorological hazards, which can influence farmers to either reduce production or cease production altogether based on the level of impact or cumulative impact of several events.

Hydro-meteorological hazards in Jamaica have been a major problem for small farmers and still continue to disrupt production, income generation and contribution to the Gross Domestic Product (GDP) (Barker 1993; Spence 1996; Spence 2008; Spence 2009; Mohan 1990; Campbell et al. 2010; Campbell and Beckford 2009; Barker and Beckford 2008). Small-scale farmers tend to have less than five acres of farm land at their disposal (MAL, 1963), but the area of land under cultivation that defines a small-scale farmer has been adjusted to under five hectares (Spence 1999). Smaller farm plots increase farmers' vulnerability to hydro-meteorological hazards as it limits the production of farmers. In addition, the total farm size of small-scale farmers is usually the sum of several fragmented plots that are used for crop production (King and Burton 1982; Edwards 1998; Brierley 1987).

Frequent impacts of hydro-meteorological hazards

The frequency and intensity of hydro-meteorological hazards have been increasing constantly over the past two decades. This is evident in the number of hurricanes, tropical storms and droughts that have impacted the Caribbean region and specifically Jamaica. Recent climate variability is often seen as the sole cause for the increase in frequency in hydro-meteorological hazards (Taylor et al. 2002; Barker and Beckford 2008, Beckford et al. 2007; Campbell and Beckford 2009; Campbell et al. 2010). However, the increased frequency in the impact of hydro-meteorological hazards could also be associated with the cyclical increase and decrease related to the El Niño/La Niña phenomena influencing conditions over the Caribbean region (UNEP 2002; UNEP 2000; Campbell and Beckford 2009; Campbell et al. 2010).

The location of Jamaica within the tropics makes small-scale farmers more vulnerable to the effects of these meteorological hazards. Jamaica is located in the Greater Antilles which makes it vulnerable to hurricanes, as a number of storms normally pass in close proximity to the island (Méheux et al. 2007; McGregor et al. 2009; Taylor et al. 2002; ECLAC 2004). The frequency of hurricane and storm activities have also been increasing over the last two decades. Spence (2009) highlighted that 57 percent of all hurricane activities affecting Jamaica have occurred in the last decade.

The impacts related to drought events are not as extensive as those related to hurricanes and tropical storms. Barker and Beckford (2008) refer to the slow onslaught of droughts as insidious in terms of the impact to the agricultural sector. Despite the localized trend in drought impact especially in rain shadow areas in Jamaica, droughts may last for prolonged periods in which the cumulative impact of the event can be quite significant. There are three types of droughts: meteorological drought, hydrological drought and agricultural drought. Meteorological drought refers to the degree of dryness in relation to the average rainfall measured over a period; hydrological drought examines the level of stream flow and water levels in storage facilities such as reservoirs and dams; and agricultural drought assesses plant moisture while considering falling rainfall totals or water supply (Spence 2009; Campbell and Beckford 2009; Campbell et al. 2010). Spence (2009, 15) further elaborates that the "vulnerability of the agriculture sector to drought coincides with periods of low rainfall which occur between the bi-modal peaks of the rainfall regime". These distinct bi-modal peaks in May and October effectively influence the growing pattern among small-scale farmers who rely heavily on rainfall as their main source of irrigation. Prolonged dry conditions may extend from December to March/April of the following year, which often reduce agricultural production.

Hydro-meteorological hazards affect the production of small-scale farmers' household economics and also the time period it takes these farmers to re-cultivate their farm plots (McGregor et al. 2009; FAO 2002; Campbell and Beckford 2009). The difference in recovery period among small farmers results from the degree of impact, amount of agricultural loss, loss of income and the resource base of individual farmers. These factors, when taken into account at the same time, affect the amount of time it will take each small farmer to successfully replant his/her farm plot(s). In addition, the recovery period usually affects the income earned and the livelihoods of farmers (Campbell et al. 2010; McGregor et al. 2009).

The recovery period is of utmost importance as it can give insight for future growth among small-scale farmers or production within the agricultural sector. The expectation of future growth can be based on the recovery period which depends on the impact of hydro-meteorological hazards among small-scale farmers. However, the recovery period at times can be reduced based on assistance from the government, family members or other farmers (McGregor et al. 2009). Unfortunately, small-scale farmers usually lack resources that would influence faster recovery periods. This lack of resources increases the time period it takes individual small-scale farmers to re-cultivate farm plots (McGregor et al. 2009; Chen and Taylor 2002, FAO 2002).

The period of time between the impact of the event and the start of the replanting process can determine the amount of particular crops that would be available for both the domestic and export markets. Berkes et al. (2003) and McGlashan et al. (2008) highlight the concern that the growth period of crops should also be considered since small-scale farmers mostly grow crops for the domestic market. This is important as the growth periods of different crops vary. The recovery period of farmers and the growth period for crops could be used to calculate the cumulative recovery time among small farmers. This would aid in the prediction of crop production for the domestic market based on the expected cumulative recovery time.

Effects of hydro-meteorological hazards on crop production

Although losing the status of the most vibrant industry and number one contributor to the GDP, the agricultural sector remains an important one for a considerable percentage of the Jamaican population as it relates to employment. "Between 2001 and 2006, the percentage of agriculture to total GDP dropped from 6.7 to 5.9%" (McGlashan et al. 2008, 15). Spence (2009) argues that the increasing intensity and frequency of storms affecting farmers have contributed to the decrease in contribution of the agricultural sector to the GDP (Figure 2).

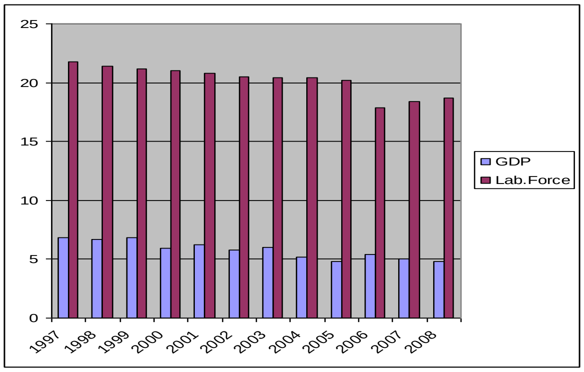

Figure 2: Contribution of Agriculture to GDP and employment in Agriculture (1989-2009). Source: Spence 2009

This reduction is evident by examining the impact of specific hydro-meteorological hazards on domestic crop production and foreign exports. There is a clear correlation between reduced employment rates and contribution of agriculture to GDP based on the year of impact, such as Hurricane Ivan in 2004, Hurricane Emily in 2005 and Tropical Storm Gustav in 2008. In addition, Tauger (2011) emphasizes that the farming population globally has been decreasing. "In 2004 the agricultural sector contributed J$13.8 billion to Jamaica's economy but damages caused by the impact of Hurricane

Ivan amounted to J$8.5 billion or roughly 62 percent of agricultural earnings for that year" (Spence 2009, 1).

Small-scale farmers constitute a large percentage of the farming population in Jamaica (Spence 2008; Spence 2009; McGregor et al. 2009; Campbell et al. 2010). However, due to the small size, location, topography and fragmentation of farm plots, production among small-scale farmers is usually less per hectare than that of large-scale farmers. However, their contribution towards domestic production and foreign export should be highlighted as they are as significant as the large-scale farmers.

This importance of agriculture is typical of Crofts Hill which produces export crops such as sugar cane and yam along with several domestic crops such as lettuce, cabbage and sorrel.

McGlashan et al. (2008, 14) explained that Jamaica:

> "has encountered serious food shortages after devastating hurricanes. In 1988, Hurricane Gilbert left US$4 billion in damage, 40% of it to agriculture which was left in shambles. As a result of Hurricanes Charley and Ivan in 2004, 190,000 tonnes of sugar cane were lost and 100% of the banana crop, causing damage amounting to $85 million. It took three months before agricultural produce was again available. In 2005 Hurricanes Emily and Dennis exacerbated the damage, while in 2007 Hurricane Dean resulted in further damage amounting to $3.7 million. The banana industry always suffers the most from hurricanes. After Hurricane Dean the banana chip industry had no raw material to use for over six months and the factory had to diversify into making chips from breadfruit and cassava to survive. No banana was imported for fear of diseases."

If small-scale farmers were to take an extensive period to re-cultivate their farm plots after specific hazard events, then production for the period after the event would be reduced until they are able to re-cultivate farm plots to maximum production. Therefore, agricultural production will be affected for the period of time that the farm plots are left idle, which creates more stress on active farmers (both small and large scale farmers) to supply existing markets both local and foreign as demand increases. When demand outweighs supply, market prices tend to increase for various crops (McGregor et al. 2009; MOA 2010; FAO 2002). However, when supply outweighs demand, there is usually a 'glut' on the market in which farmers are forced to reduce the price of their produce thus losing the profitability of that particular crop. Increased demand usually occurs directly after the hazard event in the case of hurricanes and storms while it may occur throughout the entire drought event. On the other hand, the 'glut' in supply is often associated with a boom in crop production immediately after the occurrence of a hydro-meteorological hazard.

Although small-scale farmers have been trying their best to overcome the challenges of hydro-meteorological hazards, the impact of these hazards continues to affect crop production (Ahmad 1997; Barker 1993; McGregor et al. 2009; Spence 2008; Spence 2009; Campbell and Clinton 2009; Campbell et al. 2010). For most small-scale farmers, agricultural production is the only means of survival and as such, any impact from hydro-meteorological hazards will also affect farmers as well. The impact from these hazards will always vary over time and from location to location. However, at times the impacts from these hazards are so significant that most farmers in an area will be affected. This provides the opportunity for research to be done to determine specific impacts. Recommendations provide the best means possible to combat the challenges that exist with hydro-meteorological hazards among small farmers. The Agricultural Disaster Risk Management (ADRM) Plan developed by Spence (2009) seeks to ensure that the impact of hydro-meteorological hazards is reduced by providing farmers with the tools necessary to reduce the impact of hazards and the recovery period after hazard events.

The main components of the ADRM Plan outline a number of strategies and activities to be used in the agricultural sector to reduce the impact of hydro-meteorological hazards (Spence 2009). Mitigating, preventing and preparing for the impact of disasters on the agricultural sector are important to the pre-impact phase of the hazard event. The promotion of an appropriate and effective emergency response to the impact of hazards and disasters after the event acts as an efficient way of reducing losses. In addition, ensuring the timely and effective recovery and rehabilitation from the impacts of disasters is essential to the ADRM to reduce the recovery period of farmers' crop production after a hazard event. In addition, the establishment of a monitoring and evaluation framework will effectively measure progress in ADRM in which future adjustments can be made. Based on the increased impacts of hydro-meteorological hazards over the last decade, it was imperative that such a plan be developed and implemented.

Coping mechanisms of small-scale farmers to re-occurring hazards

Over the past decade, a number of studies have been carried out to seek best practices and effective adaptation measures that can be employed in different locations to reduce the level of impact before and after a hazard event. This includes work done by Edwards (1998), Henry (1999), Thomas-Hope et al. (2000), Beckford et al. (2007), Beckford and Barker (2007), Beckford (2009), Campbell and Beckford (2009), Campbell et al. (2010), Spence (2008) and Spence (2009). To reduce crop loss resulting from hydro-meteorological hazards significantly, small-scale farmers should be open minded in accepting changes to their farming practices. Small-scale farmers are not the easiest of groups to embrace innovation and mitigation measures within their occupation. This is especially true among the elderly population (Woodsong 1994; Beckford et al. 2007; Beckford 2009), who can be regarded as laggards who are the last group within an innovation model to accept new knowledge. This is often attributed to their years of farming along with the wealth of local/indigenous knowledge they have among themselves. As such, it is essential for policy makers to include local knowledge to aid the development of new coping mechanisms for small-scale farmers (Beckford et al. 2007; Beckford and Barker 2007; Beckford 2009; Spence 2009). Spence (2009, 46) highlighted that:

> "the identification and promotion of good practices as a strategy in ADRM is an emergent paradigm in agricultural disaster loss reduction. While the identification process seeks to document existing measures that can be replicated for advancing the DRM agenda, its focus on local and sometimes indigenous measures is relatively new. One of the attractions of this new focus is its capacity to embrace local, often inexpensive coping strategies and integrate them into DRM plans, thereby promoting the participation of and partnership with local communities."

This approach would seek to transfer best practices that are cost effective in increasing the crop production of small-scale farmers.

Coping mechanisms vary from farmer to farmer and area to area, and may or may not be expensive to implement based on the type of coping mechanism and the resource base of the farmer. Coping measures/mechanisms refer to activities done by a farmer before or after a hazard event to reduce its impact. Cooper et al. (2008) highlight that the resource base of a farmer will ultimately influence the type of coping measure employed and the time period it would take for the farmer to re-cultivate his farm plots.

This was re-iterated by Campbell and Beckford (2009) and Campbell et al. (2010) in arguing that farmers react differently to the impact of hazards whether before or after based on their economic well-being.

However, in order to achieve sustainability within the agricultural sector, it is imperative that farmers use adaptive measures rather than coping mechanisms. In this regard, Cooper et al. (2008) argue that adaptive measures are more sustainable and suited for impacts over a longer period of time, while coping mechanisms are more suited for impacts over a short period of time. By employing adaptive mechanisms rather than coping mechanisms, farmers would be able to increase the economic viability of their crop production. Campbell and Beckford (2009) highlight that both coping and adaptive mechanisms, when employed before and after a hazard event, significantly reduce the recovery period of farmers. Spence (2008) provides a list of good practices that can be employed by farmers to reduce losses to crop production.

Impacts from hydro-meteorological hazards can be reduced once the necessary precautions are taken. It is important for small-scale farmers to adapt best practices which have been used by other farmers and have succeeded where loss reduction is concerned. This would increase production output, economic earnings, financial security as well as food security. This ought to be the way forward for a country that relies heavily on the agricultural sector.

Small-scale Farming in Crofts Hill

In understanding small-scale farmers, factors such as age, gender and period of involvement should be examined. Farm plot characteristics are usually unique for small-scale farmers as holding size, topography and land ownership which differ from large-scale farmers. The perception of worst and best production years provides an insight into events that would have been responsible for such perceptions. This section assesses farmer's age, gender, period of involvement, farm plot characteristics, crop production along with the worst and best production years.

Farmer's age, gender and period of involvement

In Crofts Hill, males dominate where farming is concerned as evident in the number of males versus the number of females that participated in the research. The sample had 82 percent of the respondents being male and 18 percent being female. Agriculture in the context of Jamaica has always been dominated by male farmers (Woodsong 1994; Barker 1993). The senior farmers had experience with multiple hazards, which facilitated a good understanding of the impacts of hydro-meteorological hazards. They had long involvement in farming and years of living within the community and thus had the best experience with hydro-meteorological hazards and their impacts on the agricultural sector. Forty-one percent of the respondents were over the age of 65 years, 30 percent were between the ages of 56 and 65 years, and the remaining 29 percent were younger than 55 years.

With age comes experience especially when you are within a particular occupation for a period of time. The period of involvement in crop production among the small-scale farmers was significantly high. Fifty-five percent of the farmers were involved for over 30 years, 31 percent were involved between 11 and 29 years, and 14 percent were involved for less than 10 years. The sample selected was ideal for this particular research as a significant percentage of the small-scale farmers in the sample were over the age of 60 years which is higher than the national average for farmers in Jamaica. This provided the researcher with the opportunity to collect information from farmers who have been affected multiple times. In addition, the small-scale farmers had on average more than 30 years of farming experience and had local knowledge (Brierley 1987) of the hydro-meteorological hazards which have affected the community.

All the respondents stated that they were full-time farmers although some farmers stated that they operated a part-time grocery shop to provide supplemental income. Most of the farmers were also the head of the household. Primary education was the predominant level among the farmers as the school system was much different from what we are accustomed to in today's society.

Farm plot characteristics

Land tenure and land fragmentation of farm plots are very important factors which may affect the economic viability of crop production among small-scale farmers. In the Caribbean, land fragmentation is often associated with small-scale farmers (Brierley 1987) and was observed in Crofts Hill. Land fragmentation can cause farmers' agricultural lands to be located over a wide area. In Crofts Hill, the fragmented farm plots vary in slope topography, which influences the type of crop grown as well as the labour needed to manage each plot effectively. Farm plots located on slopes are not easily accessed by the old farmers, which plays a vital role in crop production within the study area.

From the data collected, 65.8 percent of the 225 farm plots recorded were between 0 and 2 acres and did not allow for large-scale crop production. Farm size varied from farmer to farmer with most farmers cultivating fragmented farm plots. The small size, topography and fragmentation of farm plots affect the use particular machinery that would normally enhance land preparation. Land fragmentation was evident as 73 percent of the farmers had more than one plot at different locations within the community; 41 percent and 20 percent had 2 and 3 farm plots respectively (Figure 3). However, 27 percent of the respondents had only one farm plot in cultivation.

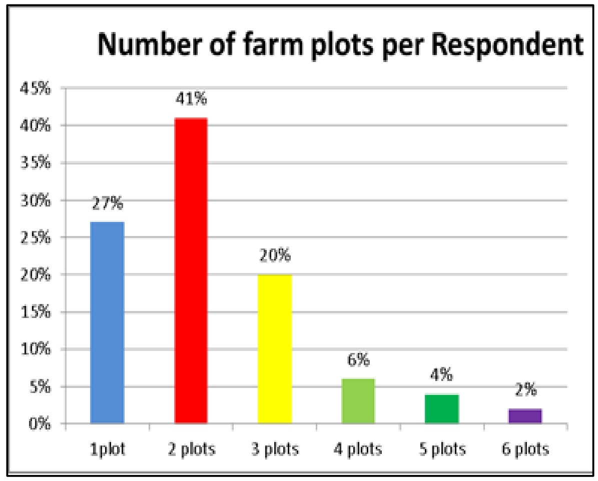

Figure 3: Number of farm plots per farmer

In addition, land tenure has the potential to affect a farmer's interest to incorporate advancements as the land may not be directly owned by them especially where plots are rented (3.1%), leased (13.3%) or family land (37.3%). On the other hand, farmers who own farm plots are more likely to invest and show more interest in crop production since they would not have to worry about eviction. Economic viability is more likely when farmers are able to make decisions that will not be affected by land tenure (Brierley 1987) and the size of farm plots where one can only take full advantage of the land available to them. A number of farmers during the focus group discussions and questionnaire administration complained that their (or someone they knew) cultivation was interrupted when family members opted to claim equal share of family land. Issues of this nature have affected the agricultural sector as it relates to crop production in which future decreases in crop production and output may occur.

Crop production

Small-scale farmers in Crofts Hill cultivate a variety of crops which are suitable for the area. Sugar cane, cabbage, sweet pepper, hot pepper, sorrel, yam, ginger and tomato are among the crops that farmers reported were most profitable to them. Most of the crops identified are supplied to the domestic market while sugar cane is mainly for the export market. During cultivation and reaping periods, farmers provided assistance through labour agreements with each other. In the past, farmers usually considered day-for-day services for free, but recently, farmers have indicated that persons who are now practicing day-for-day services were asking for payment. In other cases, farmers did not receive any assistance and had to pay workers or employ family members.

Although crop production among small-scale farmers in Crofts Hill has been decreasing steadily, farmers are still interested in agricultural production as it is their main source of income. Several factors that affected crop production were identified by the small-scale farmers in which some of these factors are similar to those that affected annual income. Natural hazards (23%) and high production costs (42%) where the two main factors identified by the respondents (Figure 4). Other factors which influenced a change in crop production include land fertility (5%) and land availability (10%). However, 16% of the respondents reported more than one factor which affected crop production while 4% of the respondents stated that nothing affected their crop production.

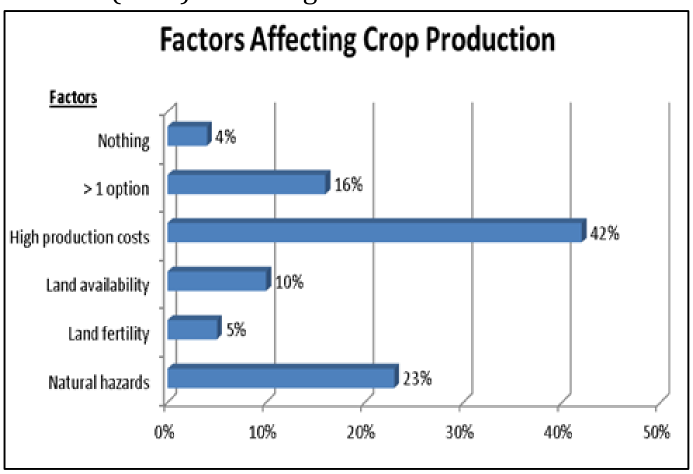

Figure 4: Factors noted by Farmers which Affect Crop Production

For the most part, most farmers relied on rainfall as other means of irrigation seemed farfetched or too expensive to consider. As a result, farming within Crofts Hill can be said to be heavily reliant on suitable climatic conditions. However, without rainfall these farm plots would suffer more from the two dry seasons experienced in Jamaica. In other cases where farmers are located along steams or near ponds/wells, they rely on those sources more because of the availability of water from those sources as well as the proximity to farm plots.

Hydro-meteorological Hazards and Agriculture

Direct and indirect impacts from hydro-meteorological hazards have affected the income and recovery period of small-scale farmers. The income earned, needed to re-invest, is limited thus resulting in lower crop production. The frequent occurrence of hydro-meteorological hazards has also contributed to a declining industry. Coping mechanisms are known to reduce hazard impacts and should be explored by small farmers in reducing their recovery period. This section assesses income, extreme hydro-meteorological hazards affecting production, direct and indirect impacts of hydro-meteorological hazards, coping mechanisms, recovery periods and the frequency of hazard events in relation to small-scale farmers.

Income

The economic viability of agriculture seems to be decreasing among small-scale farmers in Crofts Hill, Clarendon. This is a result of the decreasing production levels along with the income earned. Although showing more interest and having spent more time in the fields, the end result does not equate to effort being exerted. Over the past five years, annual income from crop production among small-scale farmers has highlighted this relationship. The annual income earned influences the decision-making process, 50 percent of the respondents indicated that they earned under $60,000[2]. Twenty-eight percent of the respondents earn between $60,000 and $89,999, 18 percent earn $90,000-$199,999 while only 4 percent of the respondents earn over $199,999 (Figure 5).

Compared to the income earned in the last five years, it is evident that income among the small-scale farmers has decreased. Five years ago, 33 percent of the respondents earned under $60,000, 37 percent earn $60,000-$89,999, 21 percent earn $90,000-$199,999 while 9 percent earn over $199,999 (Figure 5).

Irrespective of the type of crop grown, several factors were mentioned as the main cause for the change in the annual income earned among small-scale farmers. These factors vary among farmers: 18 percent of the respondents reported that they cultivated fewer farm plots, 5 percent reported that they changed the type of crop, 10 percent added that the price of the crop affected their income, 19 percent attributed the loss of annual income to natural hazards while 4 percent stated that praedial larceny influenced their annual income change. However, the majority of the farmers (44%) reported that the high production costs associated with farming affected the income earned (Figure 5). As a result, the financial security and socio-economic responsibilities of the small-scale farmers were affected due to the significant loss of income over the past five years.

The impacts of hydro-meteorological hazards in the past ten years were quite profound as was indicated in the level of damage sustained among small-scale farmers. As expected, the crop damage from the worst hurricane/tropical storm experienced was higher than the damage suffered from droughts. Eighty-seven percent of the small-scale farmers expressed that more than 50 percent of their crops were damaged by the worst hurricane/tropical storm and 13 percent indicated that 100 percent of their crops were damaged in this way (Figure 6 and Plate 2).

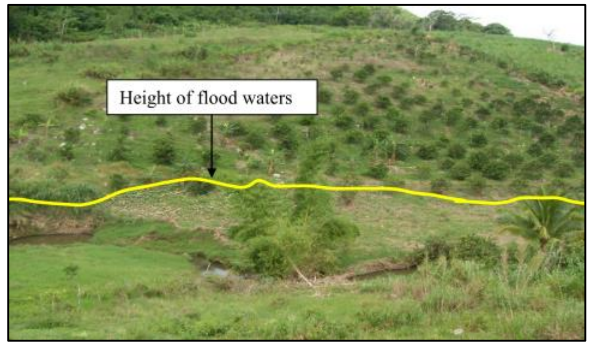

Plate 2: Flooding of farm plot caused by June 2011 flood rains

On the other hand, 6 percent of the respondents experienced 100 percent crop damage during the worst drought, 48 percent experienced more than 50 percent crop damage, and 46 percent experienced 50 percent or less crop damage (Figure 7). It is evident that small-scale farmers suffer more damage from hurricanes and tropical storms than they do from drought events. The level of damage suffered highlights the vulnerability of the agricultural sector along with the farmers involved. The potential impact of meteorological hazards to the agricultural sector should be of importance to policy makers since domestic and export crop production provides jobs, income and contributes to Jamaica's GDP.

Direct and indirect impacts

The time of impact of hurricanes/tropical storms and droughts can affect the different production periods/phases of small-scale farmers. Respondents stated that the worst hurricanes/tropical storms affected plant growth, the reaping period, the quality of the crop and their recovery period.

[2] Figures in this section are in Jamaican dollars.

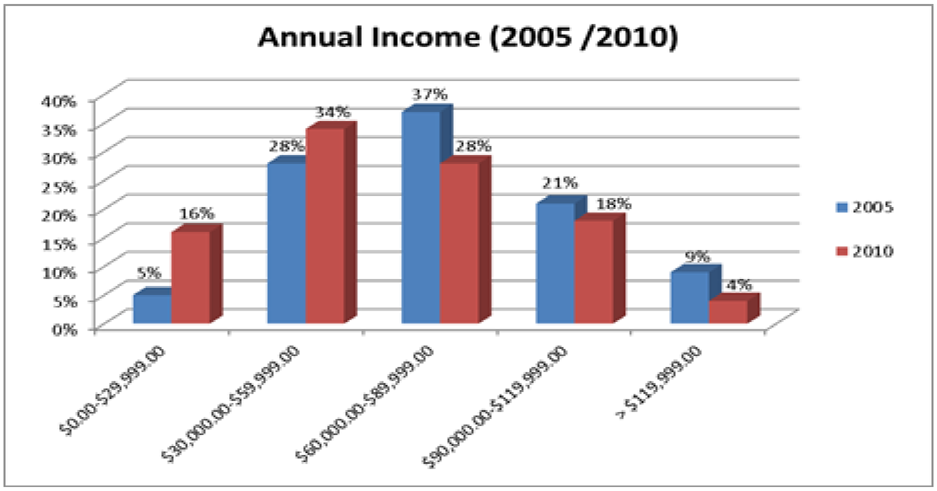

Figure 5: Comparison of Annual Income of Farmers in 2005 and 2010 (J$)

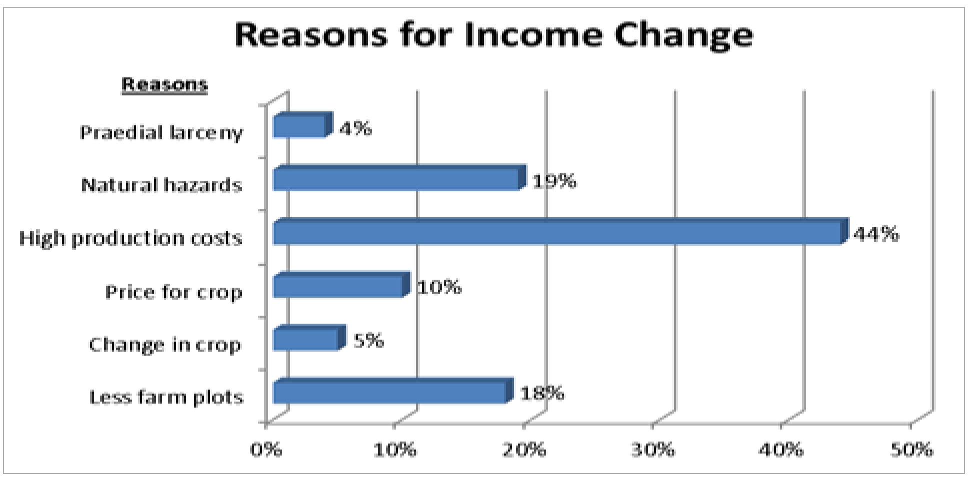

Figure 6: Reasons for the change in income

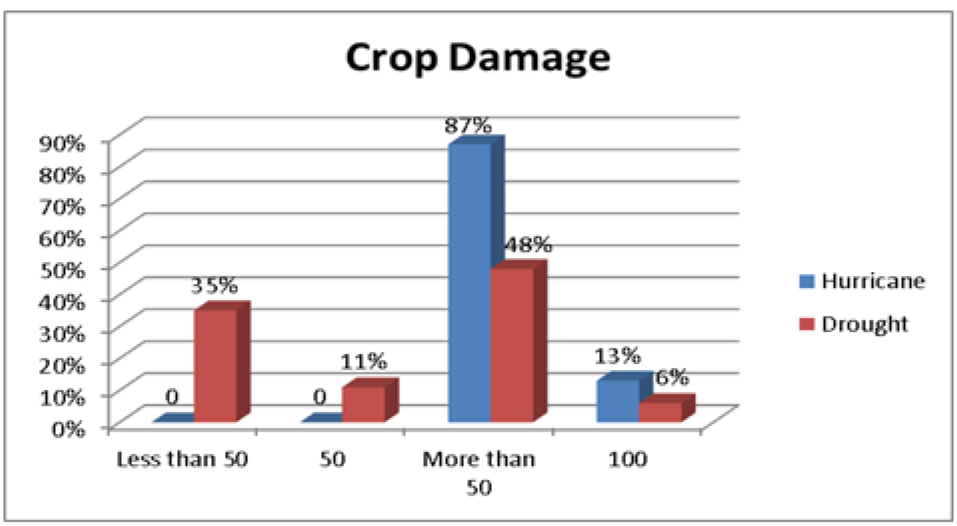

Figure 7: Crop damage from the worst hydro-meteorological hazard experienced

Output in production would be reduced and in most cases would result in a decline in income which would affect the next growing period (Plate 3). It was highlighted during the case studies and focus group discussions that crop production is reduced as small-scale farmers are unable to cope with the damages sustained. This is also evident in other areas where crop production is of importance where crop production is scaled down during and after the occurrence of a hydro-meteorological hazard (Campbell and Beckford 2009; Campbell et al. 2010).

Plate 3: Flooding of farm plot cause by blocked sink hole after June 2011 flood rains

In addition, beyond the direct impacts on the agricultural sector, hurricanes and tropical storms may also affect household operation directly and/or indirectly. The primary direct impact of hurricanes and tropical storms on small-scale farmers is damage to houses. This is often associated with the strong winds which at times can remove roofs of buildings depending on the intensity of the storm. Financial problems and food provision were indirect impacts which were highlighted by 29 percent and 18 percent of the respondents, respectively. In addition, 49 percent stated that every aspect of their household operation was affected by hurricanes and tropical storms. Various aspects of the household were also affected by droughts: financial problems (45% of respondents), provision of food (14%), water shortage (9%), every aspect (17%) while 15% of the respondents stated that their households were not significantly affected. A number of these household impacts occur indirectly from losses sustained from farmers' crop production. Each of these impacts is unique and threatens the well-being of small-scale farmers.

Coping Mechanisms

Having experienced several meteorological hazards throughout their involvement in crop production, it is imperative that small-scale farmers develop or establish coping mechanisms to mitigate or recover from the impacts of these hazards. However, based on the interaction and responses of the small-scale farmers, most of the coping mechanisms employed were geared towards recovery rather than mitigation of impacts of hydro-meteorological hazards. As a result, 29 percent stated that they replanted crops, 11 percent requested assistance, 6 percent accessed saving to recover from the hazard event. However, 45 percent of the respondents had to adjust their routine operations whether on the field or in the household while 9 percent did nothing to cope with the impacts from these storms.

Similarly, the small-scale farmers also found several ways to cope with the effects of droughts. Twenty percent of the respondents replanted crops, 44 percent adjusted routine operations, 5 percent sought assistance, 10 percent accessed savings, 3 percent irrigated the fields more than usual and 15 percent did nothing to cope with the impacts of droughts.

Based on the responses given, attention is given to hydro-meteorological hazards only during or after the event. If more focus was given to the pre-impact phase of the hazards, the related impacts would be reduced and then small-scale farmers would require fewer recovery mechanisms.

Despite losing crop production to re-occurring hydro-meteorological hazards, small-scale farmers receive very little assistance from family members/friends or government agencies. The Rural Agricultural Development Authority (RADA) and the Ministry of Agriculture (MOA) are responsible for the provision of assistance to farmers. All respondents reported that they did not receive any assistance from any government agencies whether to mitigate or recover from the impacts of hurricanes/ tropical storms and droughts. On the other hand, only 13 percent of the respondents received assistance from family members/ friends. The majority of the respondents did not receive any assistance from family members/friends and had to the cope with the effects of hurricanes/tropical storms and drought (87% and 94% respectively) on their own (Figure 8).

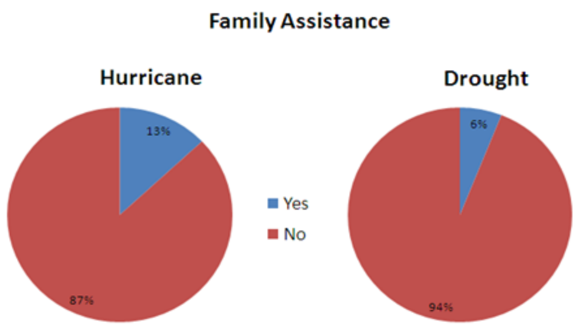

Figure 8: Family assistance received to aid with hazard impact

As it relates to assistance received for hurricanes/tropical storms, 11 percent of small-scale farmers got financial assistance while 2 percent got seedlings to replant their farm plots from family member/friends. In order to deal with the conditions of drought, 6 percent of the respondents received financial aid. During one of the focus group discussions, farmers highlighted that it was much harder for farmers who did not receive assistance to cope with the effects of meteorological hazards. This is mostly due to the poor resource base among small-scale farmers (Campbell et al. 2010; Campbell and Beckford 2009) and the inability of government agencies to provide assistance where necessary.

In order to reduce to impacts of drought events, the small-scale farmers in Crofts Hill have relied on several different coping mechanisms. Respondents implemented the following actions:

- irrigated their fields more (27%)
- stored water (17%)
- practiced mulching (4%)
- planted fewer crops (2%)
- reared livestock (2%)
- planted more resistant crops (1%)

Almost half (47%) did nothing to cope with the impacts of drought events. A number of these mechanisms have been employed by other small-scale farmers in other farming regions in Jamaica (Spence 2008; Spence 2009; Campbell and Beckford 2009; Campbell et al. 2010). However, other coping mechanisms could also be adapted as one could employ more than one mechanism to mitigate the resulting impacts of droughts. Much work has been done in the area of coping mechanisms and adaptation measures which have been used to reap successful results (Spence 2008; Campbell et al. 2010). Without the implementation of mitigation measures, small-scale farmers will be more vulnerable to the significant impacts of hydro-meteorological hazards.

Recovery Period

The continuation of crop production by small-scale farmers after the impact of a particular hazard is marred by what is known as a recovery period. As expressed before, the recovery period represents the amount of time it takes a farmer to re-cultivate his farm plots after a hazard event. Sixty four percent of the respondents indicated that their recovery period was less than 6 months, 34 percent took 6-12 months and 2 percent stated that their recovery period was more than 12 months after a hurricane/tropical event (Figure 9). Compared to drought, farmers take a longer period to re-cultivate farm plots after a hurricane or tropical storm as a result of more severe impacts. Eighty-one percent of the respondents indicated that their recovery period was less than 6 months, 17 percent took 6-12 months and 2 percent stated that their recovery period was more than 12 months after a drought.

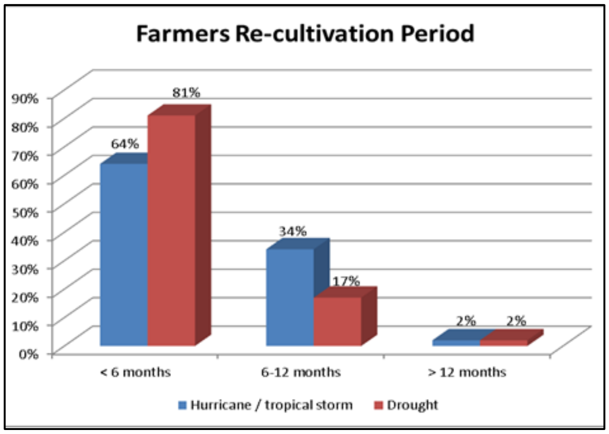

Figure 9: Re-cultivation period after impacts of hurricanes/tropical storms and droughts

This has serious implications since small-scale farmers are the main contributors to domestic crop production in Jamaica, which is vulnerable to natural hazards. The length of time it would take farmers to re-cultivate farm plots and the time it takes for plants to reach maturity could affect food security. In addition, Crofts Hill is a main supplier of sugar cane to the Worthy Park sugar factory (Burrell 2010), in which a prolonged recovery period could affect the quantity of sugar produced. As such, measures should be implemented by policy makers to reduce to recovery period of small-scale farmers after hazard events, thereby increasing their resilience.

Recommendations and Conclusion

Future of crop production

Although negative impacts have been sustained, interest in crop production still remains high among the small-scale farmers. As such, it was reported by 77 percent of the respondents that they would be able to increase their crop production. However, 23 percent claimed that they are not capable of increasing their current levels of output in crop production. This is mainly due to the average age of small-scale farmers in Crofts Hill. Most of the farmers are not able to invest the money and time that is required to effectively cultivate farm plots. In addition, even where money is not a problem, acquiring the necessary labour force to perform specific duties may be a problem.

Respondents who indicated that they could increase their crop production indicated the means by which they would be able to do so: increases in the amount of crop produced, acquisition of more farm plots, use of more fertilizers and the acquisition of more labour were the main ways to increase crop production (Figure 10). The implication is that the area under cultivation and production would increase.

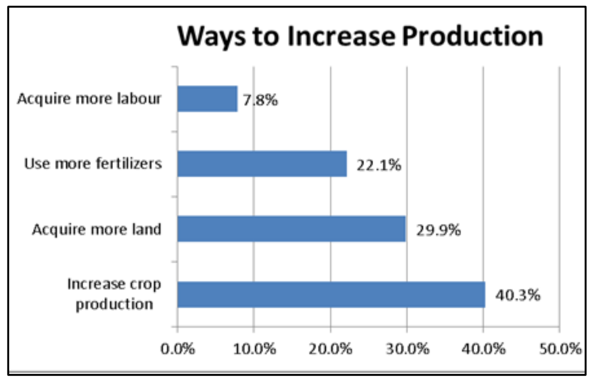

Figure 10: Ways to increase crop production yields

Based on continued support or the lack thereof and the period of involvement, small-scale farmers had varying views on the future of crop production. Sixty three percent of the respondents stated that there was a future for crop production while the remaining 37 percent stated that there was no future for crop production based on the economic and social factors affecting small-scale farmers. This is a major concern as it is possible that small-scale farmers who do not see a future in crop production may not be interested in re-cultivating their farm plots (Plate 5). The potential of farmers to go out of production is quite high and was highlighted on more than one occasion. Approximately one third of the respondents indicated that they knew of small-farmers who had gone completely out of crop production.

Plate 5: Previous farm plots now left idle

Respondents felt that future crop production was affected by:

- potential for income generation
- high demand for particular crops
- belief that farming is no longer
- youths not interested in crop production
- praedial larceny

In addition, a few respondents indicated that their only reason for engagement in future crop production was that they had nothing else to do.

Recommendations

Small-scale farmers usually have a low resource base which makes it difficult to cope with the impacts of hydro-meteorological hazards. Although farmers find it hard to access loans in general, the small-scale farmers in this research gave a different account. Sixty-seven percent of the respondents stated that access to low interest or cheaper loans would be of moderate or slightly moderate help (Table 1). However, 29 percent of the respondents stated that low interest loans would be of major or slightly major help while 4 percent indicated quite the opposite in that it would be of little or no help. As such, government agencies and the private sector should explore the option of making low interest loans available to farmers.

During or after significant impacts of hydro-meteorological hazards, the Ministry of Agriculture usually issues financial aid to severely affected farmers. However, the financial aid that is distributed by government agencies is not normally uniform. The respondents in this study indicated that no assistance was ever received after a hazard. Sixty percent of the respondents claimed that financial assistance during or after hazard impact would be of major or slightly major help (Table 1). Moderate or slightly moderate help from financial assistance was indicated by 30 percent while 13 percent claimed that financial assistance would be of little or no help.

The frequent occurrence of hydro-meteorological hazards affects the resource base and recovery period of farmers in which farm supplies may be affected. Without the necessary farm supplies small-scale farmers are usually forced to reduce or cease crop production. Sixty-six percent of the respondents indicated that the provision of farm supplies would be of moderate (32%), slightly major (23%) and major help (11%) as shown in Table 1. However, 21 percent of the respondents stated that farm supplies would be of slightly moderate help while 13 percent stated that the provision of farm supplies would be of little or no help. The provision of farms supplies in the aftermath of a hazard can reduce the recovery period of small-scale farmers.

A major hindrance in crop production has always been related to market access. Farmers normally produce crops but when reaped cannot be readily sold as there is no available market. Almost all (97%) respondents reported that market access would be of major or slightly major help (Table 1). Only 3 percent claimed that market access would be of moderate or little or no help. Policy makers should ensure there are available markets to absorb the amount of crops produced. In addition, the available

Table 1: Recommendations to increase the resilience of small-scale farmers

Recommendations	Little or no help (%)	Slightly moderate help (%)	Moderate help (%)	Slightly major help (%)	Major help (%)
Access to cheaper loans	4	30	37	22	7
Financial assistance	10	14	16	41	19
Provision of farm supplies	13	21	32	23	11
Market access	1	0	2	41	56
Crop insurance	17	24	25	15	19
Hazard forecasting and communication	3	17	18	36	26

markets should also be regulated in order to prevent gluts and shortages.

Another important recommendation that would help farmers with various aspects of crop production is crop insurance. Crop insurance would ensure a reduction in the recovery period of small-scale farmers as funds would be disbursed to re-cultivate farm plots. Thirty-four percent of the respondents stated that crop insurance would be of major or slightly major help, and 49 percent indicated that it would be of moderate or slightly moderate help (Table 1). Seventeen percent claimed that it would be of little or no help. Although much effort has been made towards the provision of crop insurance, the frequency and level of impacts related to hydro-meteorological hazards are making it hard for insurance agencies.

Hazard forecasting and communication was a recommendation that was highly favoured among the group of small-scale farmers. Sixty-two percent of respondents indicated that hazard forecasting and communication would be of major or slightly major help (Table 1); only three percent stated that hazard forecasting and communication would be of little or no help. Effective forecasting and communication of hazards can reduce related impacts on small farms by providing information that would influence small-scale farmers to implement the necessary mitigation measures and coping mechanisms.

Conclusions

Hydro-meteorological hazards continue to be a significant factor that affects crop production among small-scale farmers. A marked increase in frequency and impacts of these hazards over the last decade or two has resulted in a number of direct and indirect impacts. However, the agriculture industry continues to be vibrant albeit not with the same vigour and vitality as crop production has been fluctuating over the past ten years. Crop production among small-scale farmers is not usually seen as a viable source of economic well-being. However, while all hope in the industry is not lost, the level of interest that farmers once had is decreasing.

The small-scale farmers that are involved in crop production are as vital as the large-scale farmers. Small-scale farmers constitute a significant percentage of the farming population in Jamaica. Their contribution to the industry towards crop production has been declining but they remain significant nonetheless. Small-scale farmers have been trying their best to cope with the impacts of hydro-meteorological hazards but their efforts are proving to be futile. Low income and the unavailability of low-interest or ‘cheap’ loans are two fundamental factors that are currently restricting small farmers from achieving their true potential in crop production. However, the resilience and determination of this group should be reckoned with as most of these farmers are currently operating within the agricultural industry due to their continued involvement in crop production.

Crop production in Crofts Hill continues to be dominated by males who cultivate crops on fragmented plots, on slopes which vary from flat to very steep. A significant percentage of the farm plots are owned by the small-scale farmers which helps in the decision-making process since the thought of eviction would not be of concern. Most farmers (71%) in the community are over the age of 55 years of age which is higher than the national average. The main crops produced are sugar cane, tomato, cabbage and sorrel. The majority of the crops produced are sold to higglers, the local market and the Worthy Park sugar factory.

Crop production failure usually affects different aspects of each household, however, income generation stood out as the most affected area. In addition, impacts from hydro-meteorological hazards influence a change in routine operations of various households. However, a number of small-scale farmers employed different strategies in coping with impacts of hurricanes, tropical storms and droughts but received very limited help from family members/friends and/or the Government. Resources for re-cultivation were not readily accessible in all cases and most farmers had problems with coping with the impacts of production failure. Based on the degree of the hazard impact, farmers took different recovery periods to respond and re-cultivate their farm plots.

Another area of concern relates to the recovery period of small-scale farmers after a hazard event has occurred. It is evident that small-scale farmers within the study area took a longer recovery period for hurricane and tropical storms rather than from the impacts of drought events. Hurricanes and tropical storms occur quite frequently along with drought events which imply that farmers could be affected by another hazard event before the recovery period for the previous event ends. This would increase the recovery period required for full re-cultivation to be achieved due to the impact of successive events. In addition, based on the level of impact sustained from these hazard events coupled with the issue of viability, a number of small-scale farmers were reported to have moved from crop production to other forms of agriculture and/or to other jobs.

The recovery period of farmers was mainly influenced by the level of impact associated with the hazard event and their ability to cope with such events. A number of farmers iterated that droughts are worse now than they were in the past and claimed that present day conditions are more prolonged. In addition, the farmers also explained that they would receive scattered showers in the past but now they do not receive as much. However, the increase in the frequency of droughts did not change the behavioural action of some farmers as they did not do anything differently to cope with the drought.

In a few cases water was either stored, retrieved from further distances and/or utilized more in order to combat the adverse effects of the dry season so as to reduce crop loss or damage. In addition, some of the methods identified were of importance during the drought by farmers who were able to implement those practices (Plate 6).

Plate 6: Water being stored in drums to mitigate against drought and/or extended dry conditions

December, January, February, March and April were identified as being low rainfall months that may inflict damage to crops. May, June, September and October were identified as months with high levels of rainfall. However, other months were said to be good planting months (before or after high rainfall months) to make use of the moisture that would be present in the soil or forecasted. The change in rainfall patterns was identified by farmers as a factor affecting crop production as they complained that it affected plant growth especially during the dry seasons. In addition, during one of the focus group discussions, farmers lamented that the dry seasons are becoming more predominant because of the increase in continuous dry spells.

Small-scale farmers are faced with several issues where the economic issues far outweigh the social issues but both affect the economic earnings of small farmers. The social issues surrounding the small-scale farmers include their age, period of involvement, gender, level of education attainment, level of interest, use of indigenous technical knowledge and willingness to implement changes in the form of coping mechanisms. The economic factors include high production costs, low prices paid for sugar cane, land tenure systems, land fragmentation, inability to access loans and poor agricultural practices which also affect farmers economically. All the factors mentioned above have the potential to cause devastating impacts on the economic well-being, viability and future involvement of small-scale farmers in crop production. Despite endless efforts that have been made by family and friends, the Government of Jamaica is needed to provide assistance for particular situations where small-scale famers are usually affected. The alternative for most small-scale farmers is to either leave crop production, practice livestock rearing or to do nothing at all.

The annual income of most farmers has declined since 2005 due mainly to the decrease in crop production and to natural hazards. Hurricanes Ivan (2004), Charley (2005), Emily (2005) and Dean (2007) along with Tropical Storms Gustav (2007) and Nicole (2010) have been severe weather systems that have impacted crop production in Crofts Hill. In addition, the meteorological droughts of 1995-1997 and 2009-2010 had profound impacts on small-scale farmers' crop production. The percentage of crop damage experienced by small-scale farmers is usually higher for hurricanes and tropical storms than for drought events. In addition, the frequent occurrence and impacts related to hydro-meteorological hazards have been increasing and have serious implications for crop loss during the hurricane season and the bi-modal dry spells which can influence drought conditions.

However, small-scale farmers need to adapt to the economic constraints being experienced as a result of hydro-meteorological hazards. As such, the development and utilization of coping mechanisms to combat these problems should be given utmost consideration. Although coping mechanisms such as mulching and storage of more water during drought is practiced, the majority of the farmers often do not employ any strategy to reduce and deal with the impacts of hydro-meteorological hazards. This is an area of concern as the resilience of farmers to such hazards needs to be increased. This is the only way in which the level of impact from each hazard event will be kept to a minimum. This would also increase the economic viability of crop production among small-scale farmers.

The future of crop production will always be affected by hydro-meteorological hazards. However, policy makers and government agencies such as the Ministry of Agriculture need to pay more attention to the most affected farmers within the industry and to make the necessary adjustments to ensure that a safe and secure future for individuals who are still involved or considering becoming involved in crop production can be attained.

Large-scale farmers normally benefit from the economic viability of crop production but the same cannot be said about small-scale farmers as they are the most vulnerable group. To protect crop production for both local and foreign markets along with thousands of jobs, policy makers would have to take a holistic approach to mitigate hazard impacts while increasing the resilience of the farmer. However, the good thing is that it can be done once the necessary adjustments are made.

In addition, more research is required to give a more detailed account of relief funds for the intended population in order to influence shorter re-cultivation periods. Also, the related impacts from multiple or successive hazard events on small-scale farmers' crop production should be assessed.

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Why is a hardware financing policy mechanism like the CDM inadequate to facilitate low carbon technology transfer to many developing countries?

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Introduction

Many developing countries are in the early stages of unprecedented economic growth (MacKerron, et al., 2008; Linares and Pueyo, 2012). Consequently, there is mounting concern that future growth in energy demand and the accompanying increase in carbon dioxide emissions will be dominated by the largest, fast growing economies, such as Brazil, China and India (OECD, 2002; Garcia, et al., 2011; IEA, 2012; Pueyo, 2013). Reducing greenhouse gas (GHG) emissions in developing countries has therefore become one of the cornerstones of efforts towards a future international climate change agreement under the United Nations Framework Convention for Climate Change (UNFCCC). However, imposing caps to developing countries' GHG emissions has met strong resistance in the current negotiations as caps are perceived as a constraint to future growth prospects (Garcia, et al., 2011).

One of the key ways in which future GHG emissions can be avoided is through the development and use of low-carbon technologies. The development, transfer and use of such technologies have more positive connotations than caps to emissions, and are more widely accepted among developing countries as a way to achieve sustained growth without compromising the climate.

It is now widely recognised that one of the key ways in which future emissions can be avoided is through the development and use of low-carbon technologies (Urban and Yu, 2009; Mallett and Ockwell, 2012; Lema and Lema, 2013). The development, transfer and use of such technologies have more positive connotations than caps to emissions and are more widely accepted among developing countries as a way to achieve sustained growth without compromising the climate (Hoffmann, et al., 2008; Garcia, et al., 2011).

To date, the UNFCCC has attempted to promote technology transfer through several means: an Expert Group on Technology Transfers (EGTT), Technology Needs Assessments (TNAs), and two financial mechanisms: the Global Environment Facility (GEF) and the Clean Development Mechanism (CDM). However, these processes have been largely criticized by a growing body of literature that seeks to assess the degree to which technology transfer has either failed or materialized under these strategies (Pueyo, 2007; Haites and Seres, 2008; Dechezleprêtre, et al. 2009; Wang, 2010; Garcia, et al., 2011; Bynre, et al., 2011a; Mallet and Ockwell, 2012; Lema and Lema, 2013).

It is against this backdrop that this paper seeks to explore the extent to which financial mechanisms such as the CDM are adequate in facilitating technology transfer and fostering technological change and innovation within developing countries. To inform this discussion, this paper first engages with the broader literature on technology transfer to dissect the complexities and variations in defining and measuring this concept, before highlighting the importance of technological change/ innovation and its nexus with sustainable development.

This paper is guided by the notion that technological change and capacity building are critical elements of the technology transfer process, as well as indicators of sustainable development. Given that the twin goals of the CDM are to achieve emission reductions and to promote sustainable development, this therefore implies that the mechanism should encourage technological development and innovation in its intended context.

It is within this analytical framework that the remainder of this paper sets out to examine the nature in which technology transfer has occurred in CDM projects, and whether the current approach contributes or diverges from the wider insights suggested by literature on technology transfer and low-carbon innovation. In light of the fact that the current literature on low-carbon technology transfer has focused predominantly on the fast growing economies commonly called BRIC (Brazil, Russia, India and China), while neglecting smaller emerging developing economies (Pueyo, 2013), the arguments and ideas presented in this paper will therefore rely upon empirical evidence emerging mostly, though not exclusively from the BRICs.

Ultimately, this paper argues that the adequacy of the CDM in facilitating technology transfer is a measure of its commitment towards encouraging self-directed development and technological innovation within developing countries. Based on the balance of evidence in support of this claim, this paper culminates in determining the degree to which the CDM has been adequate in promoting sustainable pro-poor development pathways through technology transfer in developing countries.

Technology Transfer: A Need for Innovation?

Technology transfer is a highly contested and multi-dimensional concept. While no precise definition currently exists, various attempts across a wide range of disciplines have been made in conceptualising and measuring this term. Within the climate change discourse, the most frequently quoted definition is the one adopted by the Intergovernmental Panel on Climate Change (IPCC) (Das, 2011; Lumbreras, et al., 2012). The IPCC defines technology transfer as "a broad set of processes covering the flows of know-how, experience and equipment for mitigating and adapting to climate change amongst different stakeholders such as governments, private sector entities, financial institutions, non-governmental organizations, and research or education institutions" (IPCC, 2000, p.3).

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Reflecting upon this definition, it becomes apparent that the scope of technology transfer is not confined to equipment or the hardware element of a technology only, but in fact, it also constitutes a systemic and qualitative nature encompassing software elements like 'know-how' and 'experience', i.e. the knowledge dimension of a technology (Das, 2011; Mallett and Ockwell, 2012). As posited by Lumbreras, et al. (2012), these additional attributes could provide recipient countries with the capacities to install, maintain and repair imported technologies, replicate and produce lower-cost versions, as well as learn how to adapt and/ or integrate them with local circumstances and indigenous technologies. In other words, the view of technology transcends hardware, and its transfer process does not involve a one-time transaction or deployment, but rather, one that facilitates technological learning for capacity building following capital investments (IPCC, 2000; Mallett and Ockwell, 2012).

Although the holistic definition afforded by the IPCC does not appear to exclude any of the aspects desired from a technology transfer process, Zinecker (2011) contends that the current interpretation remains elusive as to what exactly is being transferred. To this end, several authors have distinguished three different flows of transferred technological content involved within international technology transfer, which may provide an indication of what is being transferred (Linares and Pueyo, 2012).

According to Bell (1990), the first flow (Flow 'A') encompasses capital goods and equipment, as well as the engineering and managerial services required to set up a system. However, this flow as largely criticized, does not enable the recipient country to utilize imported facilities efficiently, neither does it generate technological change. The second flow (Flow 'B'), emphasizes the provision of information (know-how) and skills needed to operate and maintain the equipment, but like Flow 'A', does little or nothing for developing innovation capacity, i.e. the skills and knowledge necessary to generate new technology. The third flow (Flow 'C') appears to satisfy most if not all of the critical insights underpinning the broader interpretation of technology transfer. In effect, this flow not only embodies knowledge and expertise, but it also promotes active independent learning, creation and innovation, all of which are essential for inducing technological change within the recipient country. Moreover, the characteristics implicit within these three flows (A, B and C) are also described more succinctly by Wang (2010) as: the basic level (know-how), intermediate level (know-what), and advanced or innovative level (know-why), respectively.

While the majority of low-carbon innovation and technology transfer literatures tend to underscore the need for achieving capacities embedded within Flow 'C', Mallett and Ockwell (2012) have cogently pointed out that radical innovations are not absolutely necessary in all given contexts. Instead, they argue that the ability of developing countries to create incremental and even adaptive innovations is perhaps more important in facilitating their 'catching-up' with other technological frontiers. In this regard, the capacity to innovate, be it incremental or radical, can be treated as a lynchpin for achieving technological development.

In a similar vein, the insights suggested by innovation studies also have paramount importance to developing countries particularly from the standpoint of climate change mitigation (Pueyo, 2007). As noted by Egelyng, et al. (2009), while the contribution of global emissions from many least developed countries (LDCs) is relatively insignificant at present, in the longer term, should these countries pursue their business-as-usual trajectories, this trend will undoubtedly change.

Moreover, despite the fact that these countries and like-minded fast-growing economies including China and India possess the ambition to develop low-carbon pathways, they nevertheless lack adequate financial capacity to upgrade their energy sectors for the sake of GHG reductions (Wang, 2010). As such, internationally assisted technology transfer is therefore critical to help these countries realize their role in shaping global climate change mitigation outcomes. However, as argued by many authors, the acquisition of low-carbon technologies, while necessary, is not sufficient for a sustained impact on the carbon intensity of economic activities within developing countries. In particular, from a developing country's perspective, it is critical that the firms and companies in their country own these technologies, as well as acquire the skills and expertise needed to develop indigenous low-carbon innovation (MacKerron, et al., 2008; MacKerron, et al., 2009; Urban and Yu, 2009; Byrne, et al., 2010; Pueyo, 2013). In other words, the transfer of low-carbon technologies needs to facilitate the broader process of technological change, since it is technological capacity and innovation that are necessary for sustained economic development and energy security (Ockwell, 2009; Byrne, et al., 2011a; Zinecker, 2011).

Having discussed the inherent difficulties in conceptualising technology transfer, it is important to note that measuring the outcome of this process is equally complex since technology in its broader sense has no measurable physical presence or well-defined price (IPCC, 2000). As a result, the majority of economic literature have opted to use indirect techniques of measurement such as total factor productivity (TFP), or indexes that emphasize inputs into technological achievement such as education levels, numbers of scientists and engineers, expenditures on research and development, or the number of patents granted (Lumbreras, et al., 2012). Furthermore, in light of the critical insights suggested thus far, the following section analyses the approach of technology transfer implemented by the CDM with the hope of determining whether this financing mechanism is adequate in facilitating technology transfer in its broader sense.

The Clean Development Mechanism (CDM) was developed by the Kyoto Protocol with the intention of reducing the compliance costs for industrialised countries by financing projects that reduce GHG emissions in developing countries.

The Clean Development Mechanism: A Vehicle for Technological Development or Deployment?

The Clean Development Mechanism was developed by the Kyoto Protocol with the intention of reducing the compliance costs for industrialised countries by financing projects that reduce GHG emissions in developing countries (Linares and Pueyo, 2012). Although this financing mechanism is not explicitly mandated to contribute to technology transfer, it nevertheless performs this function indirectly by financing emission reduction projects that utiltise environmentally sound technologies not currently available within recipient countries, thus encouraging sustainable development (Mallett and Ockwell, 2012). In effect, the CDM as a financing mechanism has a two-fold objective which sets out to bridge the issues of climate change mitigation with that of sustainable development. However, the CDM as a vehicle for facilitating technological change has been widely criticized as inadequate within innovation studies and low-carbon technology transfer literature (Pueyo, 2007; Haites and Seres, 2008; Dechezleprêtre, et al. 2009; Wang, 2010; Garcia, et al., 2011; Bynre, et al., 2011a; Mallet and Ockwell, 2012; Lema and Lema, 2013).

Among the most pressing arguments in support of this critique is that the CDM appears to privilege specific pathways over others, thereby reinforcing static comparative advantage. As pointed out by both Mallett and Ockwell (2012) and Silayan (2005), the investments generated from the CDM reflect an obvious cluster and bias towards a selected group of large developing countries, namely China, Brazil and India. In fact, current trends reveal that China holds the highest concentration of CDM projects, distantly followed by Brazil and India. Collectively, as of June 2010, these three nations represented 72 percent of all registered CDM projects, and 77 percent of the associated GHG emission reduction.

Coincidentally, these countries also possess high levels of absorptive and technological capacities to host low-carbon energy projects, and the projects themselves are often large-scale in nature, and restricted to a narrow range of technologies that are already relatively mature to guarantee a profitable generation of certified emission reductions (CERs) (Hoffmann, et al., 2008; Dechezleprêtre, et al. 2009; Mallett and Ockwell, 2012). In effect, the CDM tends to favour particular countries which offer the highest emission reduction opportunities and have national industries or supporting policies which complement the selected technologies currently financed. In other words, the CDM only encourages investments in specific technologies (e.g. hydro, wind, methane avoidance, biomass energy and land fill gas) that coincidentally fit well within certain settings that represent lower technical, political and economic risks. As a result, this financial mechanism reinforces static comparative advantage, thus marginalizing the poorer countries especially the LDCs which cannot replicate the favourable conditions of the BRICs (Karani, 2002; Pueyo, et al., 2011; Zinecker, 2011; Mallet and Ockwell, 2012).

As cogently pointed out by Byrne, et al. (2012), the reason for this inability to replicate, and more importantly, the CDM's inadequate contribution to technology transfer in the LDCs relates to the fact that the innovation systems of many poorer countries are presently underdeveloped, which in turn, makes the process of developing and strengthening innovation systems challenging. In effect, given the skewed distribution of CDM investments, the countries which actually desire access to low-carbon technologies are not the ones that actually derive this benefit. Hence, the CDM may be considered inadequate since it fails to facilitate technology transfer in the contexts where is it most needed. Moreover, as cautioned by many authors, since this particular pathway that the CDM privileges does not enable self-directed development or improved energy access to poorer countries, many developing countries may therefore become locked into carbon-intensive development trajectories (Byrne, et al., 2011a; Mallett and Ockwell, 2012).

In addition, this paper posits that the above-mentioned argument is closely linked to the fact that the CDM is guided by an inadequate and flawed conception of technology transfer as merely hardware deployment, rather than the broader processes encompassing technological accumulation (Byrne, et al., 2011a; Mallett and Ockwell, 2012). Furthermore, some argue that this current notion of technology transfer as a 'hardware-finance' framing is inherently due to the lack of adoption of a precise definition of technology transfer by the UNFCCC. Consequently, the CDM tends to analyse technology transfer largely on the basis of vague statements enshrined within individual project design documents (PDDs). These PDDs universally interpret technology transfer as simply the use of equipment and basic-level technological capacity (know-how) not previously available within a host country. As such, this narrow-minded view of technology transfer clearly neglects the delivery of the software elements e.g. tacit knowledge, needed for improving productive capacities, and ensuring a successful and sustainable transfer process. In other words, as suggested by Haites and Seres (2008), the CDM only focuses on rapid diffusion of equipment and basic knowledge needed to implement a project, rather than the recipient country's capacity to manufacture or develop the technology. This is the reason for the general conclusion of the CDM's inadequacy in facilitating technology transfer.

Furthermore, this paper has recognised that the CDMs inadequacy to facilitate technology transfer in a more holistic sense is not only driven by its narrow understanding of what technology transfer is, but perhaps more importantly, by the influence of political and economic interests to uphold this vague interpretation. As the old proverbial saying goes, "give a man a fish and you feed him for a day; teach a man to fish and you feed him for a lifetime" (Ritchie, 1885). This paper opines that this simple proverb has a significant analogy to the current discourse on technology transfer. As stated previously, it is the industrialized nations that mainly develop and remain in control of low-carbon technologies (in effect, they own the 'fish'). However, as implied from the growing body of literature on technology transfer, should these countries, who are coincidentally the key actors driving the CDM agenda, provide developing countries with the sort of tacit knowledge needed for innovation (teach them how to fish), this will place them at an economic disadvantage (Ockwell, 2009). To this end, this paper argues that the developed world remains fixated upon the inadequate and flawed conception of technology transfer as merely hardware deployment (access to the fish only) because this interpretation maintains their static competitive advantage over other countries that are rapidly becoming their competitors. In this regard, one can therefore conclude that the approach of the CDM is inadequate in facilitating technological accumulation within recipient countries, and at the same time, it undermines its sustainable development commitments (Linares and Pueyo, 2012). In effect, the developing world remains perpetually dependent upon 'access to the fish' from the more developed countries, rather than the ability to 'fish on their own'.

"Give a man a fish and you feed him for a day; teach a man to fish and you feed him for a lifetime." - an analogy for technology transfer

Despite the inadequate conception of technology transfer implicit within PDDs, various studies have frequently relied upon these documents as a methodology for analysing technology transfer claims under the CDM. While the findings from such studies do not explicitly demonstrate the development outcomes of CDM projects in practice, they nevertheless indicate the scope of hardware deployment and operational knowledge transferred across specific contexts. For instance, Haites and Seres (2008) analysed technology transfer claims made within the PDDs of 3,296 projects in the CDM pipeline as of June 2008. The findings from this study revealed that approximately 36 percent of registered projects (accounting for 59 percent of estimated emission reductions) claimed to involve some form of technology transfer. Moreover, 53 percent of the projects claimed to involve transfers of both equipment and knowledge, while 32 percent relied on only imports of equipment, and 15 percent claimed the transfer of knowledge only. Similar findings were also revealed by an earlier study conducted by Pueyo (2007) who analysed technology transfer in a sample of 15 CDM host countries using 938 PDDs, which represented 60 percent of the CDM pipeline in April 2007. The analysis by this study also showed that only around 35 percent of the CDM projects claimed to involve technology transfer at that time. However, more recently, a study conducted by Das (2011) suggested that the contribution of the CDM to technology transfer was minimal. After analysing 1,000 projects, Das (2011) noted that only 265 claimed to involve technology transfer. Among these, the majority (259 projects) qualified for technology transfer in which technological learning and capability building were restricted to the level of operation and maintenance of the imported equipment, whereas, the remaining 6 projects involved technology transfer in which the recipient country either collaborated with a foreign entity in developing a technology, or utilised in-country technological capacities to improve upon the imported equipment.

The main point to note here is that these three independent studies clearly showed that the CDM's approach towards technology transfer is one that is confined to the deployment of equipment and basic/ operational knowledge that are not originally available within target locations. It is for this reason that the authors of these studies have concluded that the CDM as a vehicle for technological change is grossly inadequate since the current transfer process does not equip recipient countries with the level of capacity (beyond basic/ operational knowledge) needed for facilitating technological innovation and self-directed low-carbon development. Furthermore, although a few studies (Doranova, 2009 and Disch, 2010) have extended beyond the scope of PDDs in analysing technology transfer, the general conclusion drawn from such studies is that little is still known about the development outcomes from the transfer process under the CDM. However, for the most part, these studies all posit with great certainty that the priority of the CDM remains focused on economically efficient emission reductions, whilst sustainability goals and technology transfer are treated as secondary benefits, restricted to the acquisition and financing of hardware.

In light of the above-mentioned insights, this paper has recognised that the implications of the 'hardware-finance' framing of technology transfer by the CDM are far-reaching especially in the context of China. According to Wang (2010), while the CDM has helped to increase investments in low-carbon projects in China, the nature of technology transfer (introduction of foreign equipment and training in operational skills alone) promoted under this mechanism has failed to coincide with the country's current policy priorities. Over the years, the Government of China has formulated comprehensive legislation and policies specifically aligned towards facilitating technological development at the intermediate (know-what) and advanced or innovative levels (know-why) within the country. Bearing in mind that the country already possesses high absorptive capacity in comparison to other developing nations, the desire for more advanced technological capacities that can facilitate radical innovations should not be surprising. In other words, since China already has the supporting operational knowledge for most mature low-carbon technologies, as well as access to local substitute technologies, any technology transfer mechanism designed to provide simply access to foreign equipment and basic knowledge would not encourage the form of innovation-building expected within China. Unfortunately, as echoed throughout most of this paper, technology transfer under the CDM only delivers low-level (basic knowledge/ know-how) capacity which in effect, would not contribute towards realizing China's vision, and hence, the country's low-carbon innovation is hindered.

Despite the fact that the current approach of technology transfer employed by the CDM does not foster a transformation in local contexts by facilitating innovation-building, Wang (2010) has nevertheless shown that the rate of technology transfer in the narrow sense of 'equipment deployment' has still contributed meaningfully in specific sectors of China where local substitute technologies did not previously exist. In fact, the findings which emerged from Wang's study clearly demonstrated that the projects dealing with the decomposition of the industrial gases, nitrous oxide (N_2O) and hydroflurorcarbon-23 (HFC-23) represented the highest rates (91 percent and 100 percent, respectively) of technology transfer involving foreign equipment deployment and training in operational know-how. However, for other sectors such as coal mine methane, wind power and central waste heat recovery (CWHR), the transfer rates were much lower, accounting for 26.7 percent, 28.7 percent and 6.7 percent respectively (Wang, 2010).

In light of the lower rates of technology transfer noted in the latter sectors mentioned above, this has raised yet another contentious issue within the current discourse. Notably, some authors have reported that technology transfer rates in general have been steeply declining over time among the BRICs (Achanta, et al., 2012). Within the current literature on technology transfer, this declining rate is said to be based upon the common assumption that earlier CDM projects would have contributed towards seeding local innovation (knowledge, skills and experiences) within recipient countries, upon which later projects would rely, hence, reducing the need for additional foreign technology and operational knowledge to be deployed (Haites and Seres, 2008). As a result of this assumption, the CDM tends to be praised for creating the original capacities among the BRICs for specific technologies, and therefore, the declining rates of technology transfer are misinterpreted as an indicator of innovation driven by the CDM. However, as many critics have strongly argued, this assumption is largely misleading since in their opinion, the CDM did not play an instrumental role in developing the original capacities observed among the BRICs, particularly, China and India (Lema and Lema, 2013). This conclusion was drawn mainly from the analyses of various CDM projects engaged within the wind turbine industry, one of the more mature technologies within the spectrum of low-carbon technologies currently financed under the CDM.

To demonstrate the above argument more clearly, it should be noted that the current capacities and innovation within the wind power industry of both China and India were developed following years of experimentation with a diversity of transfer mechanisms involving joint ventures, licensing agreements, foreign direct investments, and even the development of ambitious industrial and energy policies such as the 70 percent local content requirements in China (Wang, 2010; Lema and Lema, 2013). As noted by Byrne, et al. (2010), these efforts were instrumental in encouraging foreign technology providers to move their production operations to these countries, thus contributing to the level of domestic innovation evident today. Moreover, in China, wind turbines were imported and assembled in ad hoc plants from the mid-1980s, whereas the first CDM projects did not start to generate carbon credits until 2003 (Lema and Lema, 2013). In other words, the wind turbine market in China had already matured long before the introduction of the CDM.

Similarly, India had also experimented with subsidiaries and joint ventures prior to the CDM in establishing its wind turbine industry. The point to note here is that the current CDM wind power projects implemented within India and China are in fact a reflection of pre-existing transfer mechanisms. As such, the assumption that the CDM played a spearheading role in enhancing technological innovation is flawed since most of the advanced skills and capabilities within the wind sector were developed independent of this mechanism. It is on this premise that Lema and Lema (2013) have concluded that technology transfer under the CDM is more or less an effect rather than a primary cause of the domestic capabilities found in India and China. To this end, it is clear that the declining rate of technology transfer under the CDM does not reflect the success of this mechanism, but rather, the pre-existing innovation that was cultivated within these countries independent of the CDM. Such findings therefore justify the conclusion of inadequacy of the CDM in facilitating technology transfer since the mechanism clearly does not promote technological change or a transformation in local contexts.

Based on the arguments and ideas presented in this paper, it is evident that the CDM's inadequacy in facilitating technology transfer is a result of a multitude of factors driven by political, economic, social, and environmental influences. Furthermore, while the proponents behind this financial mechanism continue to advocate for the need to create enabling policy environments within developing countries (beyond the BRICs) that are conducive for CDM investments, this paper strongly opines that unless a reform of the CDM is made to broaden its understanding of technology transfer (in keeping with the wider insights suggested earlier), any changes at the national level aimed towards achieving technological change through the CDM, would remain futile. In other words, it is crucial that the CDM extends beyond its current, narrow framing of technology transfer in order to contribute more meaningfully towards ensuring self-reinforcing low-carbon development pathways among developing countries.

It is crucial that the CDM extends beyond its current, narrow framing of technology transfer in order to contribute more meaningfully towards ensuring self-reinforcing low-carbon development pathways among developing countries.

Conclusion

This paper sought to examine the extent to which the hardware financing policy mechanism, the CDM, facilitates technology transfer in developing countries. Based on the ideas and arguments presented, the CDM's approach in the transfer of low-carbon technology may best be described as inadequate.

This pessimistic outlook was based on a multitude of overlapping factors discussed within this paper. The most pressing arguments included the fact that the CDM's approach in promoting low-carbon development is one which tends to favour specific pathways over others, pathways which encompass countries possessing high absorptive capacities and large-scale projects limited to a narrow range of relatively mature technologies. As a result, the CDM reinforces static comparative advantage, thus leading to a marginalisation of many poorer countries which simply cannot replicate the enabling conditions needed for CDM investment. Hence, these countries do not benefit from improved energy access and are therefore more inclined to follow carbon-intensive pathways.

Additionally, this paper also noted that the CDM's interpretation of technology transfer is based on a flawed conception which neglects the transfer of tacit knowledge needed for innovation building. Consequently, this mechanism may be considered inadequate since it fails to foster technological change within recipient countries or enable self-directed low-carbon development. This particular argument was largely supported by empirical evidence from the wind power sectors of both China and India. The findings highlighted by various studies clearly demonstrated that although the CDM would have provided access to foreign equipment and operational knowledge within these countries, this mechanism simply did not play an instrumental role in seeding local innovation in either of the contexts examined, thus justifying the conclusion of its inadequacy as a tool for facilitating technology transfer.

Therefore, this paper purports that, unless a reform of the CDM is made to broaden its understanding of technology transfer (beyond its current 'hardware-finance' framing) to facilitate technological change and innovation, its commitment towards promoting sustainable development would remain weak.

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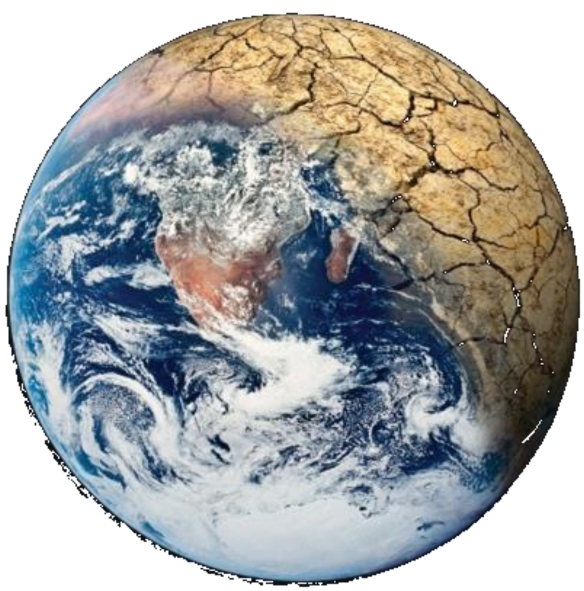

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