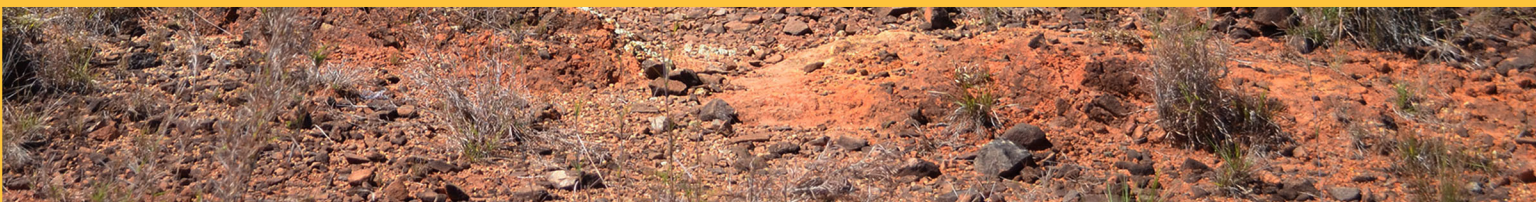
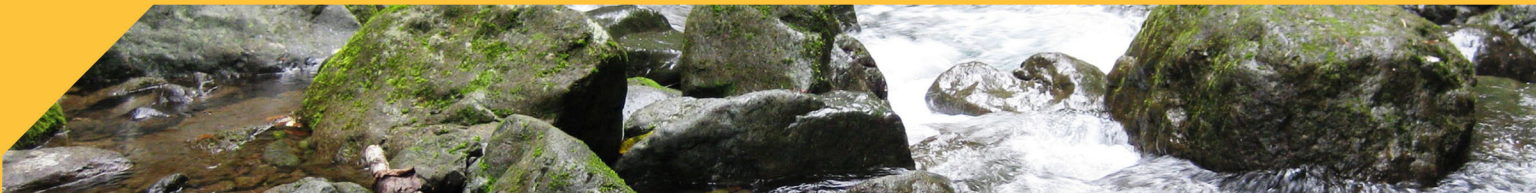


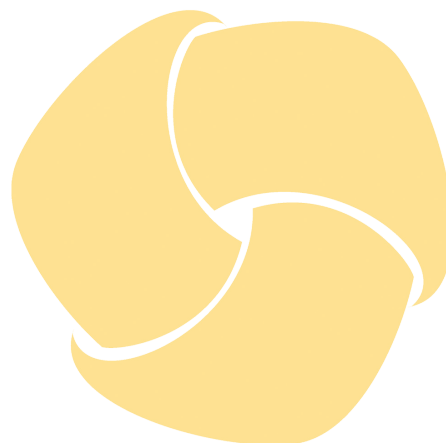


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Aims and Scope

The Climate, Disaster and Development (CDD) Journal aims to publish peer-reviewed, original research on all aspects and intersections of climate, disasters and development and their interaction. As policy makers, development workers and the general public become more keenly aware of the rising risks posed by climate hazards and disasters and their impacts on national development, the journal provides a forum for the presentation of recent research findings on these topics and their management implications. It is not only for researchers, but for anyone concerned with national development amidst climate risks and disasters.

CDD Journal is a project of the Oscar M. Lopez Center for Climate Change Adaptation and Disaster Risk Management Foundation, Inc., (OML Center) a non-stock, non-profit organization based in the Philippines. The Center is dedicated to promote a resilient society, able to cope and prosper in the midst of climate-related risks and disasters by generating science-based solutions in the area of climate change adaptation and disaster risk management.

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Table of Contents

Total Carbon Column Observing Network Philippines: Toward quantifying atmospheric carbon in Southeast Asia	1
Voltaire A. Velazco, Isamu Morino, Osamu Uchino, Nicholas M. Deuscher, Beata Bukosa, Dmitry A. Belikov, Yu Oishi, Takashi Y. Nakajima, Ronald C. Macatangay, Takahiro Nakatsuru, Shamil Maksyutov, Florian M. Schwandner, David W. T. Griffith	
Statistical downscaling of future precipitation scenarios for Agusan del Norte, Philippines	13
Karen B. Burdeos, Felino P. Lansigan	
The role of traditional ecological knowledge in the disaster risk management strategies of island communities in Cat Hai, Vietnam	23
Hoang Thi Bich Hop, Nguyen Huu Ninh, Le Thi Thu Hien	
Tourism industry financing of climate change adaptation: exploring the potential in small island developing states	33
Janto S. Hess, Ilan Kelman	
Adaptive capacity of indigenous peoples to changing climate: The case of the Aytas of Floridablanca, Pampanga, Philippines	46
Samantha Geraldine G. De los Santos, Maria Ana T. Quimbo, Dulce D. Elazegui, Margaret M. Calderon, Cristino L. Tiburan, Jr., Flordeliza A. Sanchez	
Adaptation and adaptive capacity to flooding of farming households: Insights from Mabitac, Laguna, Philippines	55
Racquel Helena D. Abagat, Efraim D. Roxas, Joan Pauline P. Talubo, Edwin R. Abucay	



Total Carbon Column Observing Network Philippines: Toward quantifying atmospheric carbon in Southeast Asia

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Abstract

TCCON (Total Carbon Column Observing Network) is dedicated to the precise measurements of greenhouse gases such as CO₂ and CH₄. TCCON measurements are used extensively for satellite validation, for atmospheric chemistry modeling, and for carbon cycle studies. With the global effort to cap greenhouse gas emissions, TCCON has taken on a vital role in validating past, current, and future satellite missions such as Japan's Greenhouse Gases Observing Satellite (GOSAT & GOSAT-2), National Aeronautics and Space Administration's (NASA) Orbiting Carbon Observatory-2 (OCO-2 & future OCO-3), and others. However, the lack of reliable validation data for satellite-based greenhouse gas observations in the tropics is a common limitation in global carbon-cycle studies that have a tropical component. The international CO₂ modeling community has specified a requirement for expansion of the CO₂ observation network within the tropics in order to reduce uncertainties in regional estimates of CO₂ sources and sinks. A TCCON site in the tropical western Pacific is a logical next step in obtaining additional knowledge that would greatly contribute to the understanding of the Earth's atmosphere and the carbon cycle. In this study, we present an assessment of a planned site in the Philippines where a new TCCON station, the first in Southeast Asia, will be installed.

Keywords: TCCON · satellite validation · capacity building · atmospheric processes · carbon cycle

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Introduction

The United Nations' World Risk Report 2016 ranked the Philippines third among countries most vulnerable to natural disasters (e.g., effects of climate change), after Vanuatu and Tonga (Garschagen et al., 2016). This is because the Philippines is highly exposed to natural hazards coupled by significant social vulnerabilities (Wannewitz, Hagenlocher, & Garschagen, 2016). Natural disasters common to the Philippines include earthquakes, volcanic eruptions, tsunamis, and other events that could be exacerbated by climate change such as flooding, typhoons, storm surges, landslides, and erosion.

Although the Philippine government has recently stepped up the country's infrastructure, civil protection, and general disaster preparedness, these alone are not sufficient without strong, internationally-supported climate change policies. To aid in policy-making, better quantification of greenhouse gas sources and sinks is needed. Southeast (SE) Asia, a region most affected by climate change, is also one of the regions with the largest uncertainties in carbon sources and sinks. For example, results of global inverse modeling showed that the largest uncertainties in CH_4 fluxes are in East and SE Asia (Cressot et al., 2014).

Carbon dioxide (CO_2) and methane (CH_4) are the two major anthropogenic greenhouse gases that contribute to climate change (Intergovernmental Panel on Climate Change [IPCC], 2013). To answer the need for better quantification of greenhouse gas sources and sinks, new space-borne satellite instruments with unprecedented measurement precision and accuracy have been launched. After the successful launch of Japan's Greenhouse Gases Observing Satellite (GOSAT) in 2009 by the Japanese Space Agency (JAXA) (Kuze, Suto, Nakajima, & Hamazaki, 2009; Nakajima, Kuze, & Suto, 2012), National Aeronautics and Space Administration (NASA) launched Orbiting Carbon Observatory-2 (OCO-2) in 2014 (Kuang, Margolis, Toon, Crisp, & Yung, 2002; Crisp et al., 2004; Miller et al., 2007; Boesch, Baker, Connor, Crisp, & Miller, 2011). GOSAT's successor, GOSAT-2, will continue this important mission and is planned to be launched into orbit by the Japanese fiscal year of 2017 (FY2017). Together with modeling studies, these measurement platforms are aimed at achieving a better understanding of sources and sinks of greenhouse gases like CO_2 and CH_4 .

However, these satellite instruments, no matter how advanced, will have to be validated by ground-based measurements. The lack of data in the tropics is a major challenge in satellite validation programs. Total Carbon Column Observing Network (TCCON) (Wunch et al., 2011) is the current "gold standard" for the total column measurements of CO_2 and CH_4 . Currently, there are 23 operational TCCON sites across the globe (Figure 1), but due to logistical difficulties, budget restrictions, and lack of site support, the distribution is uneven—leaving gaps in very important regions from

an atmospheric science perspective. For example, Figure 1 demonstrates a big gap of TCCON coverage centered around the Philippines, extending all the way from the Indian Ocean to the Tropical Western Pacific (TWP). And yet, SE Asia is a region where some of the world's most important atmospheric processes take place.



Figure 1. Operational TCCON stations worldwide (red) as of 2015. Figure courtesy of D. Feist, Max Planck Institute – Jena, Germany.

The SE Asian region is the preeminent source of tropospheric air entering the tropical stratosphere (Wright, Fu, Fueglistaler, Liu, & Zhang, 2011). According to Wright et al., (2011) "the temperature imprint carried by water vapor entering the stratosphere is disproportionately set by conditions in the tropopause layer above SE Asia" (shown in Figure 2 of Wright, Fu, Fueglistaler, Liu, & Zhang, 2011). Recent research results by Rex et al. (2014) show that an atmospheric hydroxyl radical (OH) minimum (or "OH hole") over the TWP is allowing more ozone-depleting chemicals into the stratosphere, which would amplify ozone depletion in the polar regions. This could have a significant influence on the climate of the Earth. OH acts like an atmospheric cleansing agent, removing pollutants from the atmosphere. The Philippines is located right at the edge of this OH hole and the transit region (or "giant elevator") into the stratosphere.

The lack of data in the tropical regions is also a common limitation in global carbon-cycle modeling studies. The international CO_2 modeling community have specified a requirement for the "expansion of the CO_2 observation network within the tropics" to reduce uncertainties in regional estimates of CO_2 sources and sinks using atmospheric transport models (Gurney et al., 2002). A TCCON site in the tropical regions, like the tropical western Pacific, is a logical next step in obtaining additional knowledge that would greatly contribute to the understanding of the earth's atmosphere and the carbon cycle.

This collaborative project among the University of Wollongong (UOW, Australia), the National Institute for Environmental Studies (NIES, Japan) and the Energy

Development Corporation (EDC, Philippines) is dedicated to respond to the need for a ground-based station in the SE Asian region, with the primary purpose of validating the future GOSAT-2 mission. Additionally, the Philippine site will be able to provide the much-needed validation to current and future partner missions (e.g., NASA's OCO-2 and OCO-3, Europe's Sentinel-5P), as well as data to global scientific partners through TCCON's data usage policy. This will put the Philippines on the global map of important atmospheric observation and satellite validation networks.

Site support from EDC

Energy Development Corporation, a pioneer in the geothermal energy industry with more than three decades of proven success in developing and commercializing renewable energy, will support the planned Philippine TCCON station as part of their effort to better quantify the major anthropogenic greenhouse gases that cause global warming and climate change. The Philippines is a minor emitter of CO₂ compared to most developed countries; for example, from power generation alone, the United States of America emits 80 times more CO₂ than the Philippines (www.carma.org, 2009 estimate). In contrast, the Philippines is the second largest producer of clean geothermal energy in the world (Bertani, 2016), while being one of the most vulnerable countries to climate change-induced natural hazards. This makes climate change research and adaptation to the consequences of climate change of paramount importance to the Philippines. Greenhouse gas observations are scarce in this important part of the globe. As part of its social and environmental commitment, EDC will host a TCCON station in its renewable energy power generating facility in Burgos, Ilocos Norte (Figure 2).

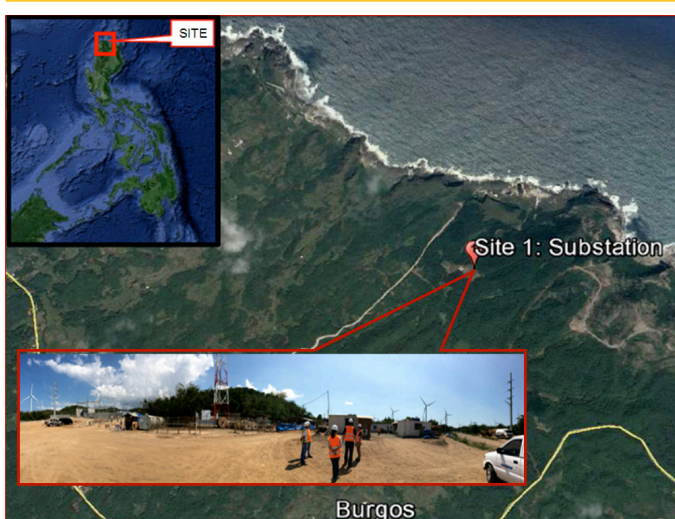


Figure 2. The TCCON container will be placed within the EDC Burgos Wind Farm Project, specifically at the substation site where technical support is available in close proximity.

EDC's environmental commitment and its collaboration with biologists and environmental scientists have led to projects and studies showcasing the flora and fauna of the Philippines and highlight the need to preserve biodiversity in the country (e.g., David, de Jesus, & Barcelona, 2011; de la Paz, Tapan, Doplon, Knipp, & Santiago, 2011; Galang, Mesina, Marciano, Tungol, & Sarmiento, 2012; Fernando, Galindon, & Ong, 2016). Supporting a TCCON station in the Philippines continues and strengthens EDC's commitment toward preservation of natural resources and protection of the environment.

Instruments and Methods for Site Assessment

This section discusses the methods used to assess the chosen location for the TCCON station. In addition to accessibility, clear skies and potential scientific contribution of the region were considered.

Site Description

Burgos is a town located in the northernmost part of Luzon island in the Philippines (18.52°N, 120.65°E), with a population of about 10,000. It is approximately 55 km from Laoag City, the capital of Ilocos Norte Province. Figure 2 shows the location of the future TCCON site.

Satellite XCO₂ Retrievals from GOSAT and OCO-2

For this study, we used GOSAT XCO₂ retrievals from NIES (version 2.xx). The OCO-2 data used are the "lite" version 7B retrievals also described in Wunch et al. (2016). We used the same spatial coincidence criterion for both satellites (400 km radius from the site). Figure 3a shows the GOSAT (cyan circles) and OCO-2 (magenta squares) soundings selected within this spatial domain (white circle). This radius terminates just before the boundaries of Metro Manila and is away from the most densely populated areas. With this criterion, measurements taken over strong CO₂ sources can be avoided and a representative XCO₂ cycle around Burgos can be observed. GOSAT soundings go back to 2010, OCO-2 started measurements in 2014, continuing and complementing the measurements of GOSAT with a finer resolution. To construct a time series of the daily mean XCO₂ within this radius, a daily-mean value was calculated by weighting the satellite measurements according to their associated retrieval errors. This included measurements taken over land and ocean.

Due to the irregular topography of Luzon island (mountains, forests, and rice fields), there are few retrievals available over land, because successful retrievals of CO₂ columns require very accurate knowledge of the light path through the atmosphere and reasonably homogeneous surface reflectance characteristics. This is difficult to achieve over rough terrain. However, there are numerous measurements

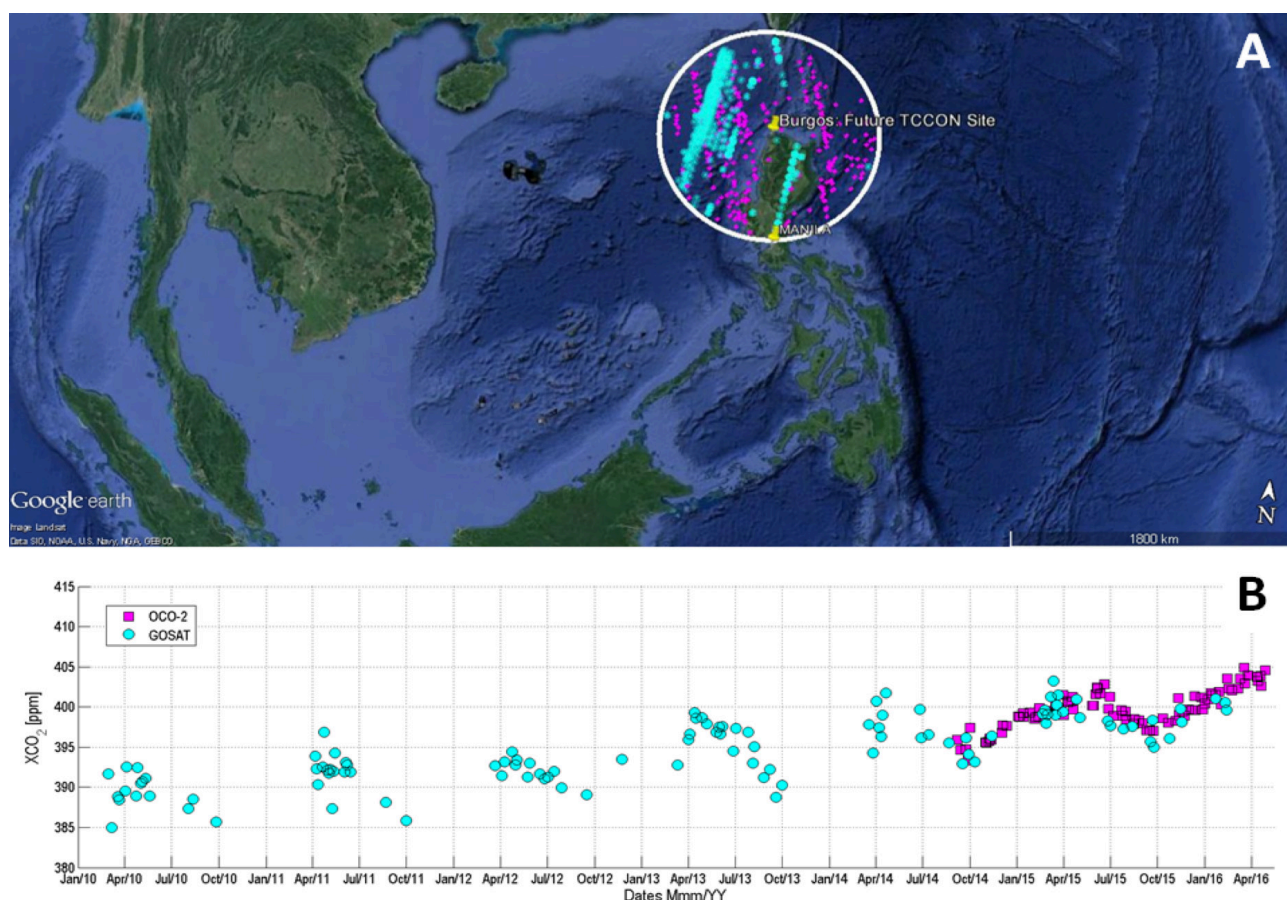


Figure 3. (a) Soundings from GOSAT (cyan circles) and OCO-2 (magenta squares) selected within a 400-km radius from Burgos (white circle) and (b) time series of error-weighted daily averaged XCO₂ values within this radius from both satellites. OCO-2 data with Warn Level flags of 11 or better were selected. For Warn Levels definition, see Mandrake et al. (2013).

over the ocean around Burgos using the satellite's glint mode. Glint mode is a technique where the specular reflection of the sun's rays over water is used. This reflection results in a very bright signal and enhances the instrument's ability to acquire highly accurate measurements, particularly over oceans.

Clear Sky Studies

One important criterion in choosing a site for a TCCON station is the clear sky probability at the site. A clear, unobstructed view of the sun is required to take measurements of solar absorption spectra from the ground. Successful soundings from satellites that look down at reflected sunlight on the earth's surface also require cloud-free skies. Therefore, we investigated clear sky probabilities using measurements from existing satellites.

MODIS Data

This study used data from the Moderate Resolution Imaging Spectroradiometer (MODIS) instruments aboard the Aqua and Terra satellites. Considered in these calculations were

pixels with clear sky or cloudy characteristics within a $0.1^\circ \times 0.1^\circ$ square centered at each site within the time frame of representative months.

GOSAT CAI Data

The study also used data from GOSAT's Cloud and Aerosol Imager (CAI, Level 2). It considered 120 overpass measurements over one year (2014) to derive clear sky probabilities within a 500 m x 500 m area (CAI pixel size). The calculations were done by matching the nearest pixels from each CAI frame, where each CAI pixel represented clear (1) or cloudy (0).

Footprint Analysis

To estimate the measurement sensitivity to surface fluxes (here called "footprints") at the TCCON site, the study employed the same method as described in Belikov et al. (2017). Forward simulations for the footprints were derived from the NIES Eulerian three-dimensional transport model (TM). The FLEXPART Lagrangian Particle Dispersion Model (LPDM) was used for backward trajectory

tracking. To initialize backward tracer simulations with the FLEXPART model, the NIES TM CO₂ concentrations, sampled at 1 km above ground at 13:00 local time, were used. FLEXPART considers atmospheric tracers as a discrete phase and tracks the pathway of each individual particle (Stohl et al., 2009). These footprints are also shown in Belikov et al. (2017).

GEOS-Chem Modelling

Footprint analysis was expanded by including GEOS-Chem (Bey et al., 2001) simulations. GEOS-Chem was run at 2°x2.5° horizontal resolution with 47 vertical levels, from January 2010 until April 2016 following a 12-year spin-up period. From 2010 to 2013, GEOS-5 meteorology was used, with GEOS-FP meteorology from the 1st of January 2013 onwards. The GEOS-Chem v10-01 CO₂ simulation is based on Nassar et al. (2010). This simulation used monthly averaged fossil fuel emissions from Open-source Data Inventory for Anthropogenic CO₂ (ODIAC) (Oda & Maksyutov, 2011) (year specific until the end of 2014, with 2015 and 2016 recycling 2014 estimates), the annual inventory of biofuel emissions scaled to 1995 from Yevich and Logan (2003), 2004 monthly shipping emissions from International Comprehensive Ocean-Atmosphere Data Set (ICODS) (Corbett & Koehler 2003, 2004; Endresen et al., 2004, 2007), 2005 aviation fuel burn emissions from Aviation Emissions Inventory Code (AEIC) (Simone, Stettler, Eastham, & Barrett, 2013; Olsen, Weubbles, & Owen, 2013), daily biomass burning emissions from GFEDv4 obtained using the GFED3 daily fractions (years after 2014 use recycled 2014 estimates) (Giglio, Randerson, & van der Werf, 2013), three hourly SiB3 balanced biosphere fluxes (years after 2010 are recycling 2010 estimates) (Messerschmidt et al., 2013) with annual net biosphere exchange based on TransCom from 2000 (Baker et al., 2006), and scaled ocean exchange from Takahashi et al. (2009) (years after 2013 are recycling 2013 estimates). The emissions inventories are plotted in Figure 4. For comparison with the GOSAT and OCO-2 XCO₂, the offset due to the initial conditions chosen for the run was corrected by matching the model average and GOSAT-measured XCO₂.

Development of a New TCCON FTS Container with LIDAR Capability

The container (L: 7060 mm, W: 2280 mm, H: 2470 mm), houses a high-resolution (HR) Fourier-transform infrared spectrometer (FTS), model Bruker 125HR (Bruker Optics Corp., Billerica MA, USA) with a maximum spectral resolution of 0.0035 cm⁻¹. This instrument is the heart of every TCCON station. A solar tracker with a CamTracker® function ensures precise and accurate tracking of the solar disc to within ± 0.1°. Two types of beam splitters enable measurements in the near infrared (NIR) region (around 670 nm to 2000 nm) and in the mid-infrared (MIR) region

(around 2000 nm to 13,500 nm). In addition to TCCON measurements in the NIR, MIR measurements will enable retrieval of altitude-profile information of several atmospheric pollutants, e.g., carbon monoxide (CO), hydrogen cyanide (HCN), ozone (O₃), and others. Four detectors will be used: silicon (Si) and indium gallium arsenide (InGaAs) for TCCON mode; indium antimonide (InSb) and mercury cadmium telluride (HgCdTe) for the MIR (plus the necessary optical filters). The station is also equipped with hydrobromic acid (HBr) and hydrochloric acid (HCl) cells for regular determination of instrument alignment. During the early stages, remote-controlled manual operation (via internet) with on-site support is planned, followed by automatic operation later, which builds upon previous automated TCCON operation experience. Also in the container is a LiDAR (Light Detection and Ranging) system capable of measuring water vapor, aerosol, and cirrus cloud profiles up to the stratosphere. It operates at two wavelengths: 1064 nm and 532 nm with two polarization channels.

A weather station, following TCCON data protocol, will measure temperature and humidity inside and outside of the container as well as wind speed and wind direction. A pyranometer will be used to measure solar radiation.

The following will be installed later: a sky radiometer, an all-sky camera (Skyview), a photometer for aerosol optical depth, and cloud measurements, as well as a liquid nitrogen (LN2) generator (for InSb and HgCdTe detector cooling).

Results and Discussions

XCO₂ Over Burgos

Figure 3b shows the time series of the daily mean XCO₂ within a 400-km radius centered in Burgos, measured from GOSAT and OCO-2. A clear seasonal cycle with a maximum around April and a minimum around October can be seen, especially during the later years when OCO-2 measurements were possible. GOSAT can measure 750 km across in one swath, leading to more regional data. However due to the pixel size of GOSAT (10 km across), cloudy skies especially in the rainy season lead to fewer data. OCO-2 has a narrow swath (10.6 km), but its smaller pixels (1.29 km × 2.25 km) may be able to “see through” clear patches amid cloudy skies, leading to more local data. Figure 3b shows the complementary nature of these two instruments.

Clear Sky Probabilities

The MODIS clear sky statistics from the different candidate sites, which were originally considered for the SE Asia TCCON station, are listed in Table 1. Figure 5 shows the clear sky probabilities calculated from the GOSAT CAI.

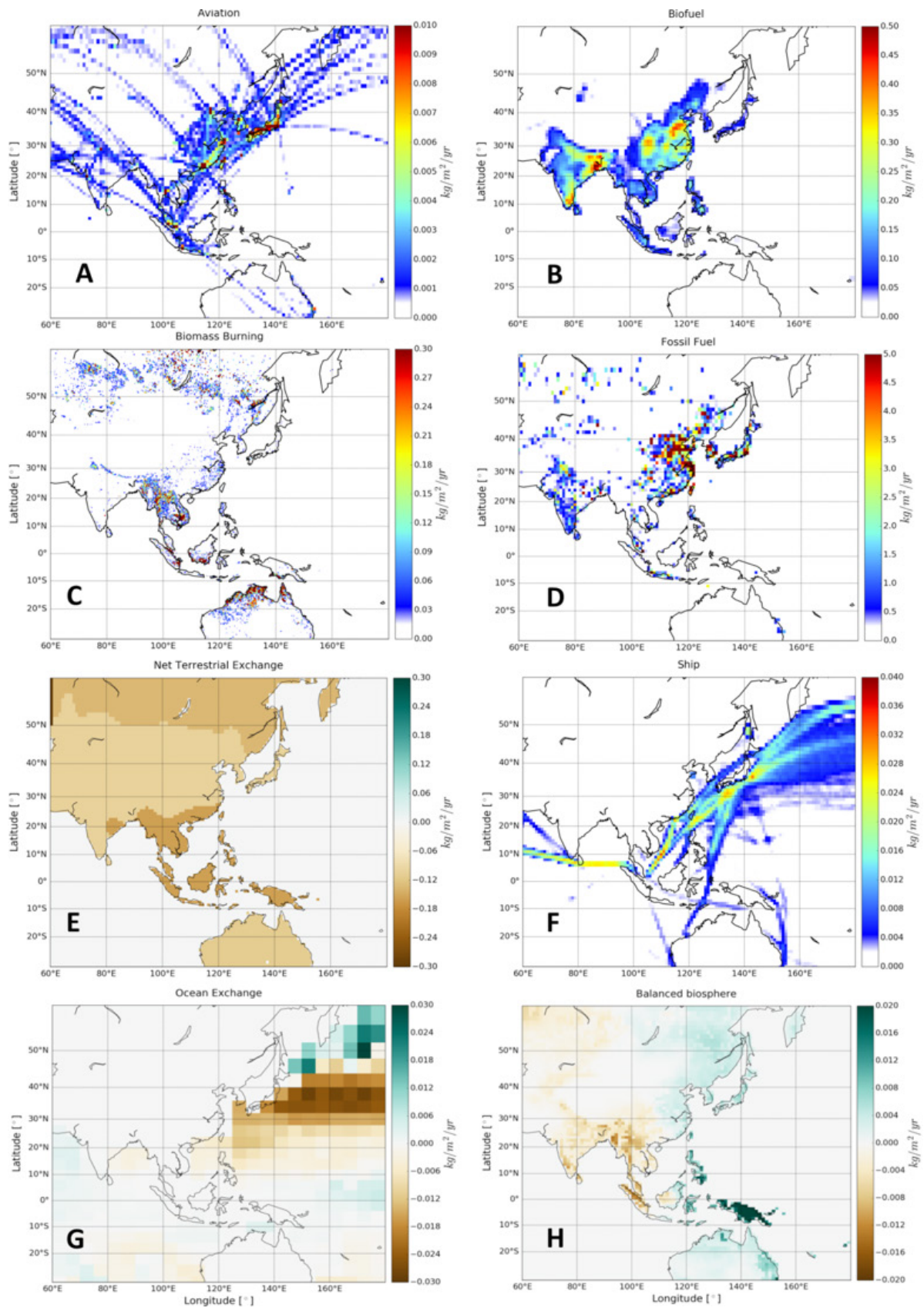


Figure 4. Year specific annual emissions used for the CO_2 simulations: (a) aviation emissions (fuel burn) summed vertically from 2005, (b) biofuel emissions from 1995, (c) biomass burning from 2014, (d) fossil fuel emissions from 2014, (e) net terrestrial exchange from 2000, (f) shipping emissions from 2004, (g) ocean exchange based on 2013, and (h) balanced biosphere fluxes from 2010.

The two other candidate sites in the Philippines (Leyte and Negros), both strategically located near the western Pacific warm pool, are also ready for a TCCON station. However, for satellite validation and for maximizing measurements over clear skies, Burgos stands out with the frequency of clear sky opportunities and being located in a prominent clear patch, as shown in Figure 5.

Measurement Sensitivity to Surface Fluxes

Table 1. MODIS Clear Pixels at $0.1^\circ \times 0.1^\circ$ (in %)

Site	Oct '12	Jan '13	Apr '13	Jul '13	Average
Burgos	58.6	69.0	59.0	11.3	49.5
Leyte	10.7	8.3	20.6	5.7	11.3
Negros	9.3	9.3	33.2	11.0	15.7
Phimai	47.3	48.1	7.2	0.0	25.6
Katotabang	1.2	1.0	2.9	24.3	7.4

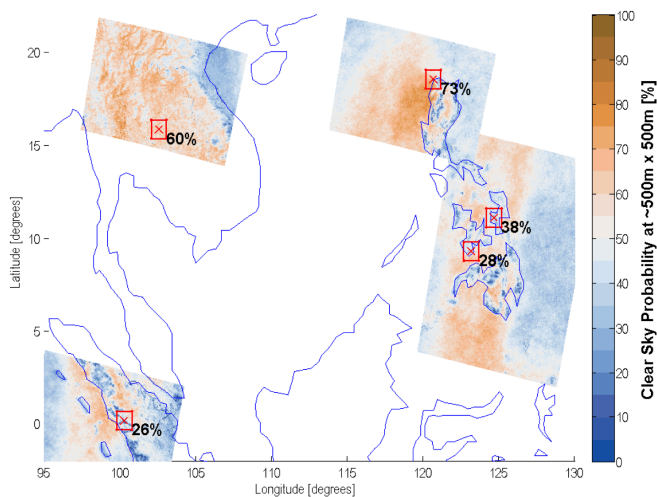


Figure 5. Clear sky probabilities calculated from each pixel (color-coded) measured by the GOSAT Cloud and Aerosol Imager (CAI). The pixel sizes are approximately 500 m x 500 m. The numbers in % over the assessed sites: Burgos, Leyte, and Negros (including two other sites Phimai in Thailand and Katotabang Indonesia), indicate the probability that the closest pixel has a value of “1” (clear) out of 120 overpasses for 2014.

Figure 6 shows that the Burgos site covers the short-term footprint of the Tropical Western Pacific. Depending on the season, the footprints also include Taiwan, Hong Kong, and parts of Eastern and Southeastern China. The spatial distribution and variability of the surface emissions around this region can be inferred from Figure 4. This demonstrates that the location of this future TCCON site will measure air with significant and variable contributions from emissions of some of the largest anthropogenic carbon sources in the world.

Model Comparison Results

The modeled XCO_2 over Burgos calculated by GEOS-Chem is shown in Figure 7, zoomed in around 2014-2016 (black line). XCO_2 data from GOSAT (cyan circles) and OCO-2 (magenta squares) are superimposed. Table 2 shows the satellite-derived XCO_2 and GEOS-chem XCO_2 differences. The model shows a closer agreement to GOSAT XCO_2 . The reason for this result is that the GEOS-Chem offset due to the initial conditions was optimized to the GOSAT-measured XCO_2 . Nevertheless, data from the model and from the two satellites capture the seasonal cycle. There is a slight drift during the later years where the model shows less XCO_2 . This is due to the 2014 fossil fuel fluxes that were recycled for 2015 to 2016, resulting in an underestimate of fossil fuel flux, and hence the CO_2 growth rate, during these years. This shows how sensitive the XCO_2 measurements are to real-world fossil fuel emissions.

Table 2. Satellite and GEOS Chem XCO_2 differences.

Months	GOSAT-Model		OCO ₂ -Model	
	ΔXCO_2 (ppm)	StDev (ppm)	ΔXCO_2 (ppm)	StDev (ppm)
SON	0.0403	0.1970	0.0806	0.2727
DJF	0.0221	0.1474	0.1033	0.3049
MAM	0.0580	0.2341	0.0833	0.2769
JJA	0.0290	0.1681	0.0543	0.2271

Performance of the 125HR: Side-by-Side Comparison with the Tsukuba TCCON FTS, Alignment, and Line Shape

A side-by-side comparison of Xgas measurements against the established TCCON station in Tsukuba, Japan (Ohya et al., 2009) was performed on the 31st of March 2015. TCCON protocols were followed for the measurements and data processing. Table 3 shows very good agreements between the Xgas amounts from both instruments. The differences are well within the accepted error budget of TCCON. Figure 8 shows a characterization of the instrument performance. The top left panel shows the modulation efficiency of the spectrometer measured using an HCl gas cell (Hase et al., 2013). This measurement procedure yields a value of about 96.5% at 45 cm OPD (optical path difference). It should be noted that an earthquake slightly affected the alignment, which could have caused the modulation efficiency to decrease from an ideal value of 100%. However, this is still in the range specified in Hase et al. (2013) and Griffith (2010). Re-alignment will be necessary upon installation in Burgos.

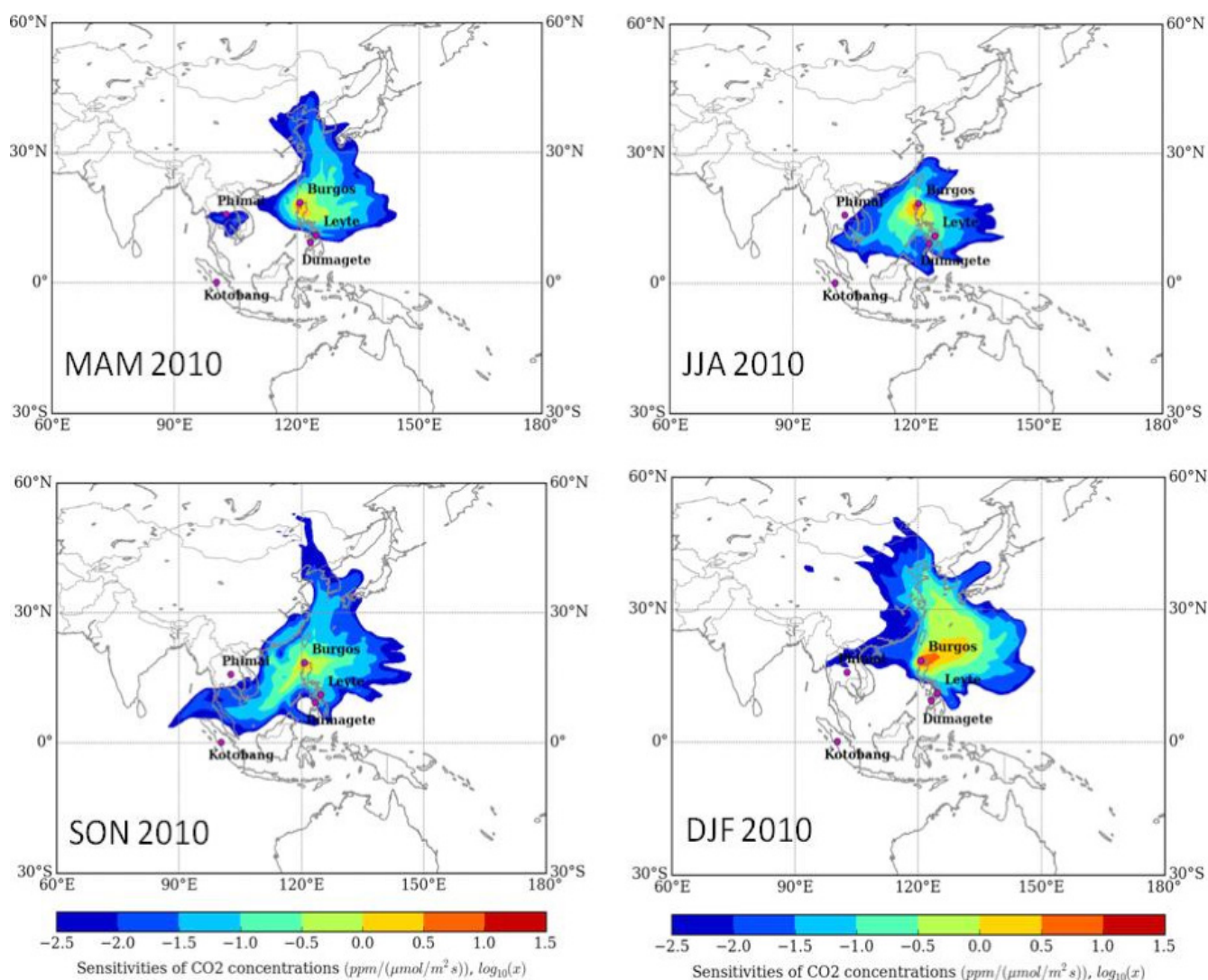


Figure 6. These panels show the sensitivity (color-coded) of the column measurements in Burgos with respect to the surrounding surface fluxes. The distribution of the sensitivity of CO₂ concentrations with respect to the concentrations in adjacent cells are expressed in ppm/(μmol/m² s). Values are calculated using the FLEXPART model with a resolution of 1.0° for the Burgos site.

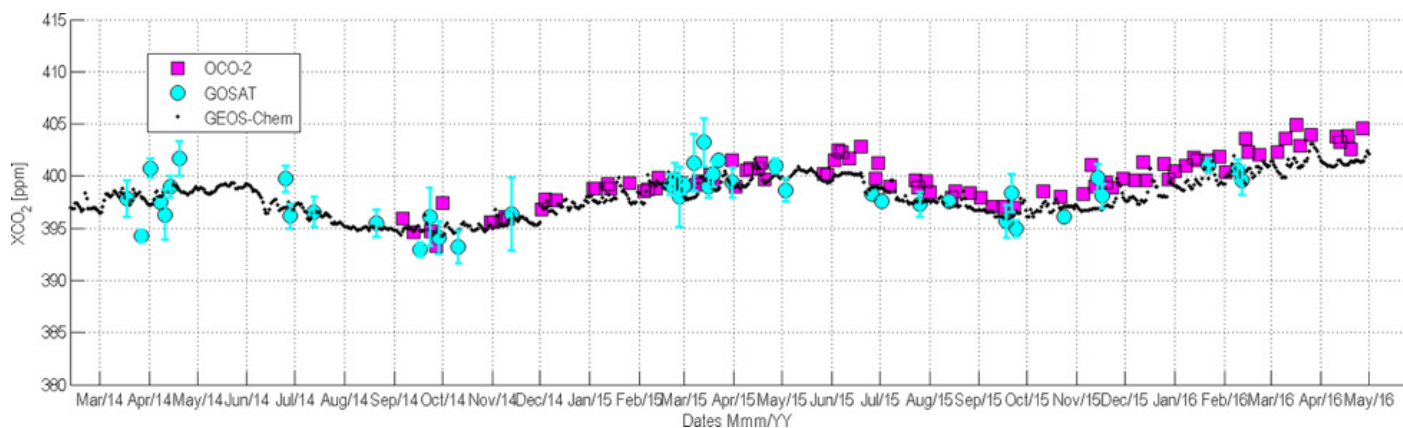


Figure 7. XCO₂ over Burgos derived from GOSAT, OCO-2, and the GEOS Chem model.

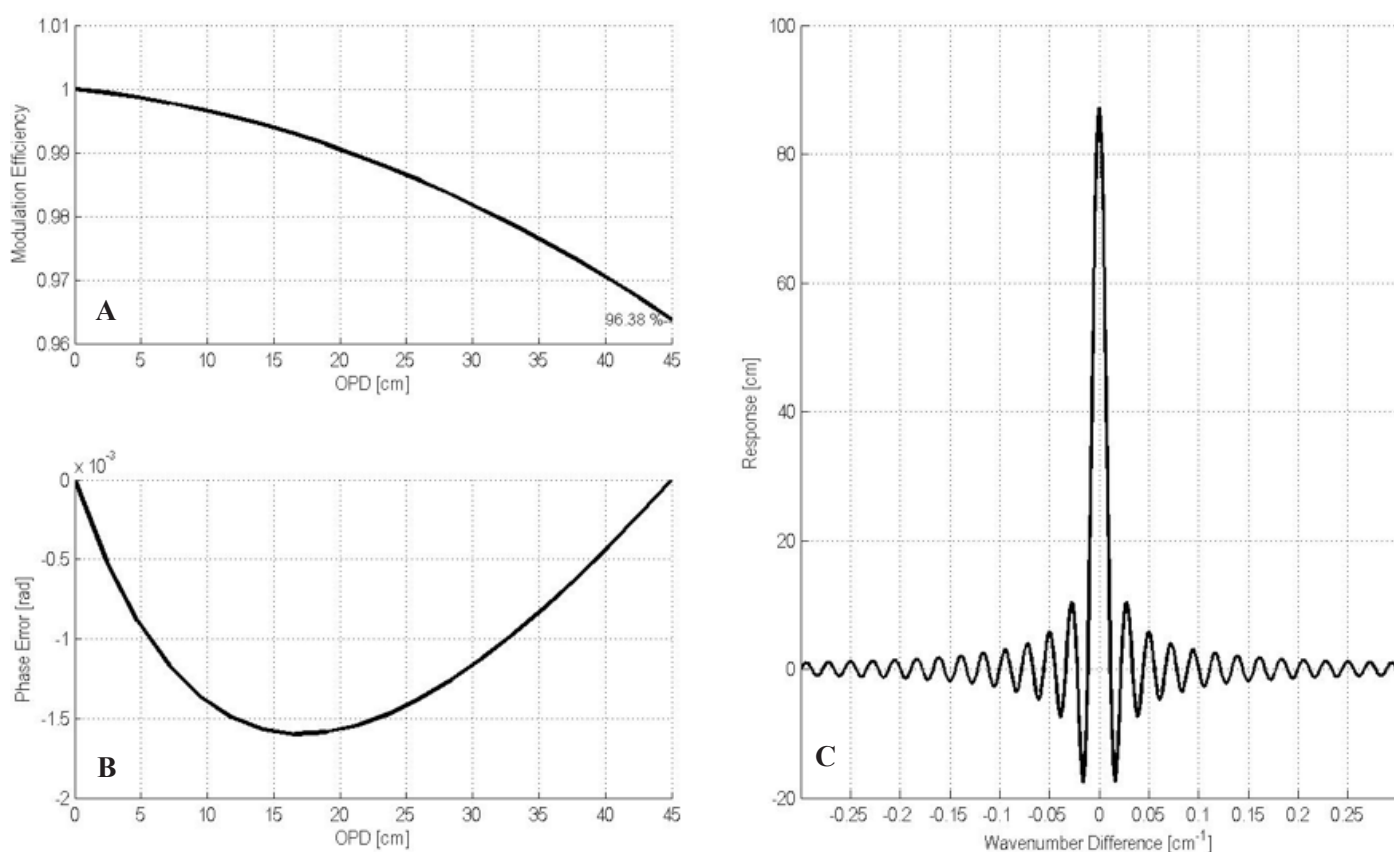


Figure 8. (a) Modulation efficiency as a function of the OPD, (b) phase error as a function of OPD, and (c) instrument line shape (ILS).

Table 3. Side-by-side comparison of Xgas measurements between Tsukuba TCCON and NIES container FTS for Burgos on March 31, 2015 at 14:42 local time.

	Container FTS for Burgos	Tsukuba TCCON FTS	Differences
XCO ₂ (ppm)	402.58 ± 0.51	402.84 ± 0.30	-0.26 (-0.032%)
XCH ₄ (ppm)	1.821 ± 0.002	1.823 ± 0.001	-0.002 (-0.055%)
XCO (ppb)	106.2 ± 0.2	107.0 ± 0.3	-0.8 (-0.38%)
XN ₂ O (ppb)	317.73 ± 0.85	320.03 ± 0.47	-2.3 (-0.36%)
XH ₂ O (ppm)	1853.2 ± 14.7	1851.1 ± 14.2	2.1 (0.056%)
XHF (ppt)	56.8 ± 0.1	56.6 ± 0.9	0.2 (0.18%)

Conclusions

This study showed an assessment of the future TCCON site in the Philippines. The study inferred from GOSAT data that the chosen site in Burgos is in a region with a prominent clear-sky patch, exceeding the calculated clear-sky probabilities of four other candidate sites in SE Asia. This condition is desirable both for satellite validation and for maximizing TCCON observations. The total column measurement sensitivity to surface fluxes at the TCCON site in Burgos was calculated to show the spatial

coverage of future measurements. GEOS-Chem modeling of the XCO₂ at the site was also done and compared with actual measurements of GOSAT and OCO-2. Satellite measurements and model simulations agree qualitatively on the seasonal variability, however the future TCCON measurements are expected to fill in important data gaps. The NIES TCCON instrument for Burgos has been tested, characterized, and compared with the established TCCON station in Tsukuba, Japan. The results of the comparison show very small differences in the retrieved total column values of several trace gases. The measurement difference in XCO₂ is well within the error budget of TCCON. The instrument arrived in Burgos, Ilocos Norte, Philippines and installation was finished last February 2017. Full operations are expected to commence by April 2017, allowing ample time for measurements before the launch of GOSAT-2.

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Statistical Downscaling of Future Precipitation Scenarios for Agusan del Norte, Philippines

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Abstract

General circulation models (GCMs) are essential tools for understanding climate behavior and projecting future global climate, but with limited applications for local vulnerability assessments, impact studies, and risk analyses. This study demonstrated the use of the statistical downscaling technique, which is computationally inexpensive and efficient in generating locally relevant data from GCMs. The 30-year records of daily precipitation data from 1981 to 2010 in Agusan del Norte, Philippines were considered to analyze the existing climatic condition of the province. Future precipitation magnitude, centered on 2020 (2006-2035), 2050 (2036-2065), and 2080 (2066-2095), were generated using a statistical downscaling technique under A1B climate scenario. Based on the analyses of annual 24-hour and 48-hour maximum precipitation, climatic conditions for present and future scenarios were analyzed. Precipitations with 24-hour duration are expected to increase by about 2-18%, 6-19%, and 15-51% for the period 2020, 2050, and 2080, respectively. Meanwhile, rainfall with 48-hour duration is projected to increase by about 7-17%, 7-18%, and 16-51% for the period 2020, 2050, and 2080, respectively. Future precipitation scenarios can help stakeholders from different sectors in the province evaluate impacts and identify tradeoffs towards implementing the most appropriate climate change adaptation strategies.

Keywords: statistical downscaling · precipitation scenarios · climate change · Agusan del Norte · Philippines

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Introduction

The Intergovernmental Panel on Climate Change (IPCC, 2013) has released a report that presents robust and significant findings about the science of climate change at a global scale, thereby enhancing our understanding of the climate system. The climate data in the report were generated using the general circulation models (GCMs), a complex mathematical representation of the major climate system components describing climatic condition at a global or continental scale. These data can be used to develop various climate scenarios capable of informing different stakeholders about the likely impacts of future climate. However, climate information at the local scale is needed to prepare and plan for the anticipated impacts and risks of projected climate change (Trzaska & Schnarr, 2014). Local-scale climate information is required in conducting sectoral analysis, for instance in the areas of agricultural production, food security, human health, local economy, and many others (Wreford, Moran & Adger, 2010; Asian Development Bank [ADB], 2011; Nelson et al., 2009).

Several methods and technologies have been developed and used to derive climate data at the local scale from the data produced with coarser resolution. Downscaling technique is now widely used to simulate climate data for a specific locality from global scale climate information supplied by GCM. This technique, which can be applied to define climate spatially and temporally, consists of several steps, assumptions to be satisfied, limitations, and advantages (Trzaska & Schnarr, 2014; Wilby & Dawson, 2007).

Downscaling has two main approaches to generate locally-relevant data from GCMs: statistical downscaling and dynamic downscaling approaches. Dynamic downscaling is used to produce a higher resolution Regional Climate Model (RCM) within a coarser resolution GCM, thereby simulating local conditions in greater detail. This approach requires intensive computing skills and high volume of data inputs to be able to generate local surface weather. Further, the approach has limited number of RCMs and model results are only available for some parts of the world (Trzaska & Schnarr, 2014; Department of Science and Technology – Philippine Atmospheric Geophysical and Astronomical Services Administration [DOST-PAGASA], 2011; Wilby & Dawson, 2007).

On one hand, statistical downscaling is efficient and does not require intensive computing skills. It uses various statistical analyses to establish an empirical relationships between local climate variables (e.g., local precipitation and surface air temperature) and large-scale atmospheric predictors (e.g., airflow strength), and the application of such relationship to the output of GCM to simulate future local climate (Wilby & Dawson, 2007; Sunyer, Madsen, & Ang, 2012). This allows

for generating climate data of different emission scenarios for a specific location.

Several provinces in the Philippines, including the province of Agusan del Norte, have experienced extreme rainfall^a events that caused massive inundation in the area as recorded by the National Disaster Risk Reduction and Management Council (NDRRMC). Many residents in the province suffered from low farm productivity and loss of lives and properties (International Labour Organization [ILO], 2011). This scenario has posed an alarming call to stakeholders since the occurrences of extreme events have now become dramatically more frequent and magnitudes have been more intense (Garrett & Müller, 2008; IPCC, 2012; IPCC 2014). To prepare for the anticipated impacts and risks brought by climate change, this study demonstrated the use of statistical downscaling approach in developing a location-specific climate scenario for Agusan del Norte, Philippines for periods 2020 (2006-2035), 2050 (2036-2065), and 2080 (2066-2095) using the Third Generation Coupled Global Climate Model (CGCM3) under A1B scenario.

Methodology

Study Area

The province of Agusan del Norte, which has a land area of 2,730.24 km², is located in the northeastern part of Mindanao Island in the southern part of the Philippines. According to the modified Coronas classification, it has a type II climate, which is characterized by the absence of a dry season but with a very pronounced maximum rain period from November to February. (DOST-PAGASA, 2011). On average, the province received an annual total rainfall magnitude of around 2,400 mm based on DOST-PAGASA historical records.

Due to its topography that lies on the eastern coast, the place is faced with the northeast monsoon, trade winds, and storms. Every year, the province is among those areas greatly hit by different typhoons that enter the country's area of responsibility according to NDRRMC. These typhoons, which commonly originate from the pacific coast (eastern part of the Philippines) and make landfall, carry heavy rains and strong winds.

Heavy rains have caused inundation in most areas of the province, especially when the water overflows from the lower sub basin of the third largest river in the country, the Agusan River, which is in Agusan del Norte (ADB, 2008). Further, hydrologic-related events such as landslides, flashfloods, and maritime incidents were also observed due to consistent heavy rains. This phenomenon has affected many people's lives and property, and posed an alarming call to different stakeholders to come up with actions addressing the impacts of flooding in the area.

^a A 300 mm daily rainfall is considered as "extreme" by the Department of Science and Technology-Philippine Atmospheric Geophysical and Astronomical Services Administration (DOST-PAGASA) (2011).

Data Collection

Thirty-year historical records (1981-2010) of daily precipitation of the province were obtained from PAGASA as baseline data to analyze the existing climatic condition. Two storm durations, the 24-hour and the 48-hour annual maximum precipitation, were considered. The weather station in the province, categorized as Airport and Surface Synoptic Station by PAGASA, is located at Bancasi Airport, Brgy. Bancasi, Butuan City, Agusan del Norte with latitude and longitude coordinates of $08^{\circ}56'48''$ N and $125^{\circ}32'36''$ E, respectively (Figure 1).

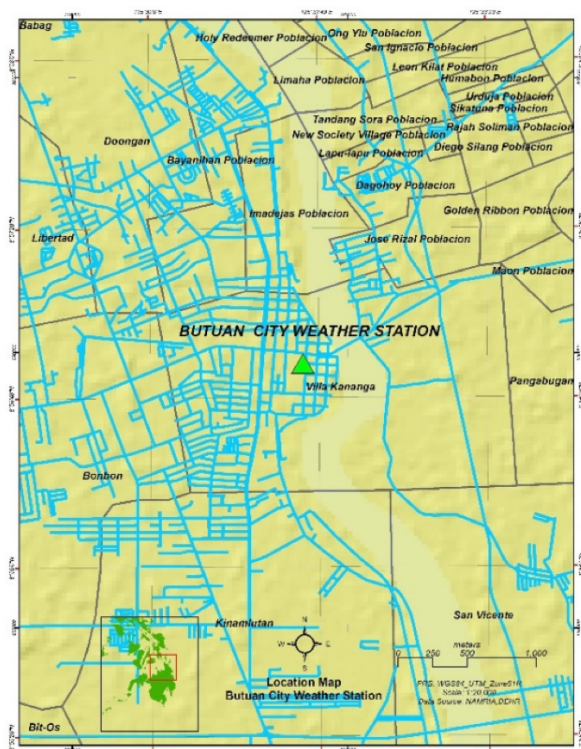


Figure 1. Location map of the airport and surface synoptic station of Agusan del Norte, Philippines.

Three time frames were considered for future climate predictions: 2020 (2006-2035), 2050 (2036-2065), and 2080 (2066-2095). Atmospheric predictor variables used were from the National Centre for Environmental Prediction (NCEP) re-analysis dataset for model calibration (Wilby & Dawson, 2007) and from CGCM3 (Flato, 2005) under a medium-range emission (A1B) climate scenario (DOST-PAGASA, 2011) for future climate modelling. They were requested and acquired from the Data Integration Access (DAI) Portal with latitude and longitude coordinates of 9.28° N and 123.75° E, respectively.

CGCM3 is a product of the Canadian Centre for Climate Modelling and Analysis (CCCma) with a new atmospheric

component, the Atmospheric Canadian GCM version 3 (ACGCM3). It was run at two resolutions: (1) the T47 version with a 3.75 degree grid cell size for atmospheric horizontal resolution and 1.85 degree resolution for the oceanic component; and (2) the T63 version which has a 2.8 degree atmospheric resolution subdivided into six oceanic grid cells (Flato, 2005).

Statistical Downscaling Process

The Statistical Downscaling Model (SDSM) version 4.2.9 software was used in this study (available at <http://co-public.lboro.ac.uk/cocwd/SDSM/>). SDSM is a free software used to produce ensembles of local climate change time series using a statistical downscaling technique (Wilby & Dawson, 2004; Wilby & Dawson, 2007). It is described as a hybrid of the stochastic weather generator and transfer function methods. It uses large-scale circulation patterns and atmospheric moisture variables to condition the local-scale weather generator parameters and utilizes stochastic technique to artificially inflate the variance of the downscaled data for a better representation of the observations (Wilby & Dawson, 2007). The statistical downscaling technique involves the following steps: variables screening, variable transformation (if necessary), model calibration, and weather and scenario generation (Wilby & Dawson, 2004; Wilby & Dawson, 2007).

In this study, a daily record of precipitation data from 1981 to 1992 (12 years) and from 1993 to 2003 (11 years) were used for model calibration and model validation, respectively.

Statistical Analysis and Evaluation of Data

Monthly mean, seasonal mean, and maximum values were computed to determine some statistical characteristics of the observed and simulated precipitation data.

Evaluation criteria between the observed and simulated data were also computed (Chen, Xu, & Gou, 2012; Batincila, 2012) such as the root-mean-squared error (RMSE) (Kelley & Keke, 2011; Makridakis & Hibon, 1995), Percent Bias (PBIAS) (Gupta, Sorooshian, & Yapo, 1999; Chen et al., 2012), Nash-Sutcliffe Efficiency (NSE), and RMSE-observations standard deviation ratio (RSR) (Moriassi et al., 2007).

Table 1 summarizes the general performance ratings for every statistic for a monthly time step established by Moriassi et al. (2007).

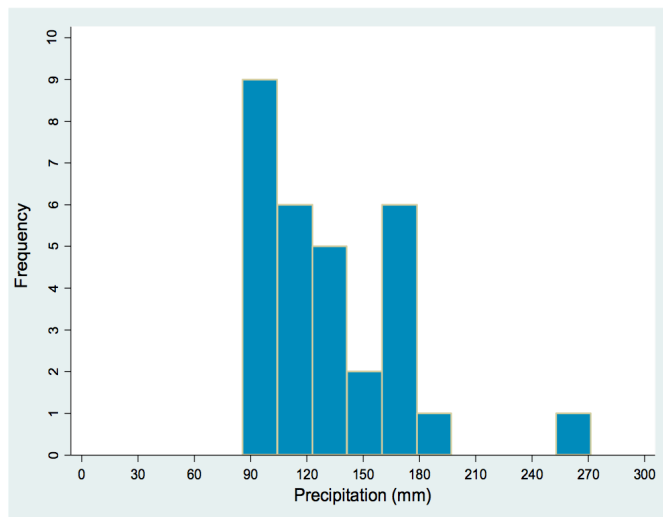
Results and Discussions

Current Climate Condition (1981–2010)

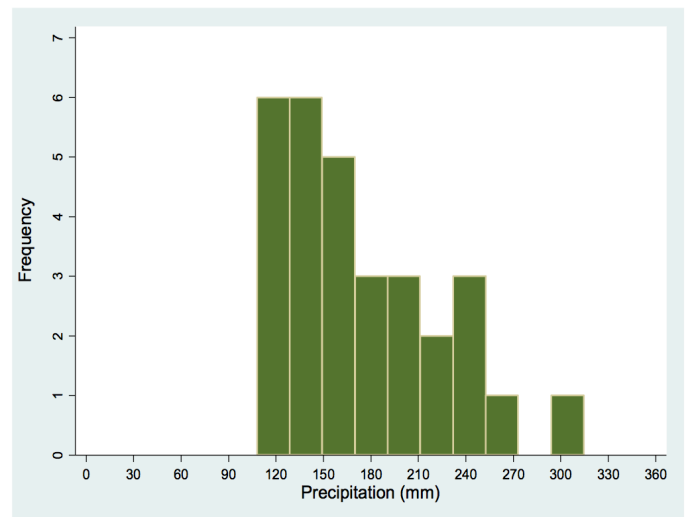
Figure 2 shows the frequency distribution from 1981 to 2010, focusing on the annual maximum 24-hr and 48-hr precipitation that occurred in the area. The annual

Table 1. General performance rating for model evaluation criteria

Performance Rating	RSR	NSE (%)	PBIAS (%)
Very good	$0.00 \leq \text{RSR} \leq 0.50$	$75 < \text{NSE} \leq 100$	$\text{PBIAS} \leq \pm 10$
Good	$0.50 \leq \text{RSR} \leq 0.60$	$65 < \text{NSE} \leq 75$	$\pm 10 \leq \text{PBIAS} \leq \pm 15$
Satisfactory	$0.60 < \text{RSR} \leq 0.70$	$50 < \text{NSE} \leq 65$	$\pm 15 \leq \text{PBIAS} \leq \pm 25$
Unsatisfactory	$\text{RSR} > 0.70$	$\text{NSE} \leq 50$	$\text{PBIAS} \geq \pm 25$



(a)



(b)

Figure 2. Frequency distribution of annual (a) 24-hr maximum and (b) 48-hr maximum precipitation data of Agusan del Norte from 1981 to 2010.

maximum daily precipitation ranges from approximately 90 mm to 270 mm for a 24-hr duration and around 100 mm to 320 mm for a 48-hr duration.

Table 2 summarizes the annual 24-hr and 48-hr maximum precipitation values recorded from 1981 to 2010. It was in 1985 that the province experienced the highest annual precipitation, which reached up to 271.6 mm and 314.6 mm for 24-hr and 48-hr durations, respectively. A La Niña event was also recorded that year, with an Oceanic Niña Index (ONI) value of -1.1 indicating a stronger La Niña event compared to other La Niña events recorded from 1981 to 2010 (Hilario, de Guzman, Ortega, Hayman, & Alexander, 2009). In contrast, it was in 1998 when the province experienced the lowest amount of precipitation of 85.8 mm rainfall within a 24-hr duration. One of the four most significant drought events recorded in the Philippines for the last two decades was in 1997 to 1998 (Hilario et al., 2009).

Statistical Downscaling Outputs

Screening of Predictor Variables

There are 26 predictor variables to choose from the NCEP

Table 2. Annual 24-hr and 48-hr maximum (max.) precipitation values (mm) in Agusan del Norte from 1981 to 2010 (Source of Data: DOST-PAGASA)

Year	24-hr max. (mm)	48-hr max. (mm)	Year	24-hr max. (mm)	48-hr max. (mm)
1981	175.8	207.6	1996	128.1	141.5
1982	110.0	139.2	1997	98.3	128.0
1983	108.8	119.2	1998	85.8	108.0
1984	127.8	149.2	1999	111.0	160.5
1985	271.6	314.6	2000	167.9	195.7
1986	147.0	244.5	2001	167.4	191.4
1987	130.3	150.3	2002	117.2	137.4
1988	191.4	211.9	2003	133.6	211.6
1989	96.3	111.8	2004	114.0	147.0
1990	93.9	122.8	2005	97.8	176.9
1991	98.2	108.6	2006	160.4	248.4
1992	94.6	169.6	2007	90.8	162.4
1993	171.8	237.4	2008	119.7	170.5
1994	168.0	189.9	2009	159.0	259.6
1995	131.8	139.8	2010	102.5	161.5

re-analysis and CGCM3, both of which were oriented to A1B scenario. Thorough assessment was done to determine the most conceptually and physically sensible predictor variables at the local weather site by performing these tasks: seasonal correlation analysis, partial correlation analysis, and scatter plots (Wilby & Dawson, 2004; Wilby & Dawson, 2007). Table 3 shows the list of the NCEP re-analysis and CGCM3 predictor variables for the precipitation data of Agusan del Norte as the predictand. The four predictor variables that gave the most desirable explained variance, correlation, and partial correlation coefficient values were selected: 850 hPa airflow strength (p8_f), 850 hPa zonal velocity (p8_u), specific humidity at 500 hPa (s500), and specific humidity at 850 hPa (s850).

Table 3. Selected NCEP/CGCM3 predictor variables for weather data generation and their description (Wilby & Dawson, 2004; Wilby & Dawson, 2007)

Code Name	Predictor Description	Precipitation
mslp	Mean Sea Level Pressure	
p_f	Surface Airflow Strength	
p_u	Surface Zonal Velocity	
p_v	Surface Meridional Velocity	
p_z	Surface Vorticity	
p_th	Surface Wind Direction	
p_zh	Surface Divergence	
p5_f	500 hPa Airflow Strength	
p5_u	500 hPa Zonal Velocity	
p5_v	500 hPa Meridional Velocity	
p5_z	500 hPa Vorticity	
p500	500 hPa Geopotential Height	
p5th	500 hPa Wind Direction	
p5zh	500 hPa Divergence	
p8_f	850 hPa Airflow Strength	✓
p8_u	850 hPa Zonal Velocity	✓
p8_v	850 hPa Meridional Velocity	
p8_z	850 hPa Vorticity	
p850	850 hPa Geopotential Height	
p8th	850 hPa Wind Direction	
p8zh	850 hPa Divergence	
s500	Specific Humidity at 500 hPa	✓
s850	Specific Humidity at 850 hPa	✓
shum	Surface Specific Humidity	
temp	Mean Temperature at 2m	
prcp	Precipitation	

Calibration and Validation of the Model

Model evaluation criteria. Three evaluation criteria were employed to assess the efficiency and accuracy of the model such as NSE (%), PBIAS (%), and RSR. These were matched with Table 1 to determine the general performance rating of each criterion. Table 4 shows the model evaluation criteria for calibration and validation processes using monthly maximum precipitation. (Chen et al., 2012; Moriasi et al.,

Table 4. Model evaluation criteria for calibration and validation processes using monthly maximum precipitation

Evaluation Criteria	Monthly Maximum		Remarks
	Calibration	Validation	
NSE (%)	99.97	79.94	Very Good
PBIAS (%)	-2.75	0.32	Very Good
RSR (%)	0.02	0.45	Very Good

2007). The model evaluated for both processes are all rated as “Very Good” in each of the three tests of accuracy used.

Figure 3 shows the closeness and intersection of observed and simulated series in the calibration process, which indicates a very good fit of the simulated data to the observation. All the tests employed in the analysis gave values that indicate that the model fitted the observed data well.

On one hand, the observed and simulated series are seen to be overlapping in the validation process as shown in Figure 4. It shows that there is an underestimation of the simulated data to the observed for the months of February, March, April, August, and September, and also an overestimation for the months of May, July, October, November, and December. However, these monthly biases are insignificant as reflected by its PBIAS (79.94%) which was rated as “Very Good” from the evaluation.

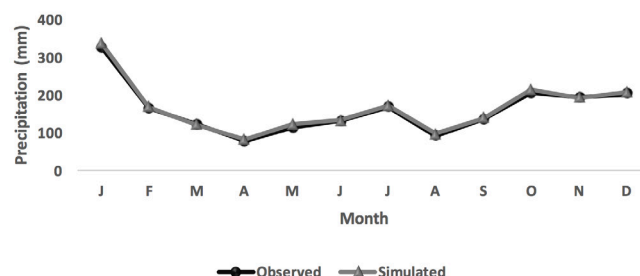


Figure 3. Mean monthly total precipitation of the observed and calibrated model for Agusan del Norte

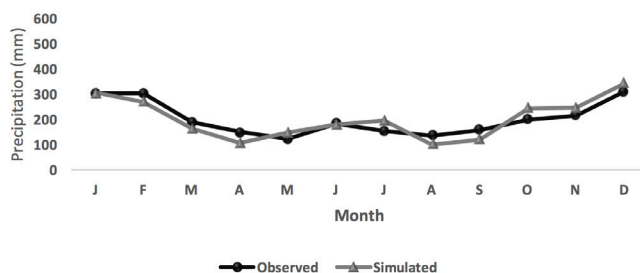


Figure 4. Mean monthly total precipitation of the observed and validated model for Agusan del Norte

Climate Scenario 2020 (2006-2035)

Table 5 lists precipitation values while Figure 5 shows the frequency distribution of the downscaled annual 24-hr and 48-hr maximum precipitation for 2020 climate scenario. It shows that for a 24-hr duration of rain, maximum precipitation could reach up to approximately 280 mm. More frequent rains with 100 mm scales are also expected in this scenario. For a 48-hr storm duration, rainfall projection could range from 90 mm to 320 mm. More frequent storm events are also projected to occur in 2006-2035.

Table 5. Annual maximum (max.) 24-hr and 48-hr precipitation values (mm) in Agusan del Norte for 2020 climate scenario (2006-2035)

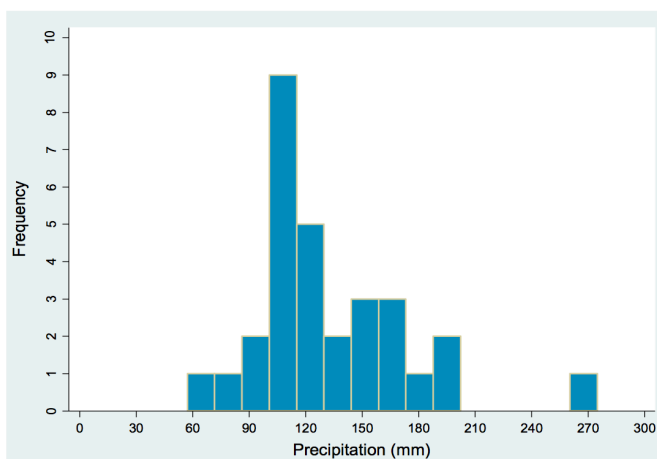
Year	24-hr max. (mm)	48-hr max. (mm)	Year	24-hr max. (mm)	48-hr max. (mm)
2006	110.2	119.5	2021	105.7	146.1
2007	164.4	210.6	2022	146.8	168.0
2008	57.2	80.1	2023	149.9	149.9
2009	102.8	156.6	2024	168.7	187.4
2010	80.1	80.1	2025	174.7	183.7
2011	87.3	140.6	2026	111.4	158.3
2012	138.4	161.5	2027	106.3	128.6
2013	140.4	151.5	2028	111.7	170.7
2014	123.3	123.5	2029	148.9	193.9
2015	89.5	100.9	2030	110.9	147.8
2016	105.7	126.6	2031	118.1	131.2
2017	163.7	217.9	2032	113.4	216.2
2018	190.3	217.3	2033	274.9	328.0
2019	192.1	212.2	2034	123.4	160.9
2020	128.6	128.6	2035	120.5	137.8

Climate Scenario 2050 (2036-2065)

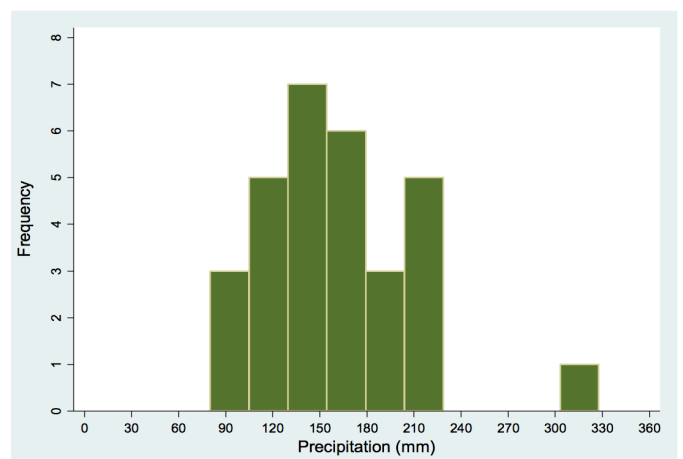
Table 6 indicates the precipitation values while Figure 6 shows the frequency distribution of the downscaled annual maximum 24-hr and 48-hr precipitation for 2050 climate scenario. It can be noticed that the distribution is concentrated within 80 mm to 160 mm rainfall magnitude, a bit higher than the 2020 projection. Precipitation magnitude in 2050 could reach up to 320 mm rainfall for a 24-hr duration, indicating more extreme events in the future. Annual maximum precipitation is projected to range from 110 mm to 330 mm for a 48-hr observation during this period.

Table 6. Annual maximum (max.) 24-hr and 48-hr precipitation values (mm) in Agusan del Norte for 2050 climate scenario (2036-2065)

Year	24-hr max. (mm)	48-hr max. (mm)	Year	24-hr max. (mm)	48-hr max. (mm)
2036	84.9	122.2	2051	86.2	122.7
2037	79.7	107.8	2052	125.6	160.4
2038	104.2	106.1	2053	103.8	126.5
2039	151.0	215.1	2054	126.0	146.7
2040	219.7	290.1	2055	182.5	198.7
2041	85.8	157.7	2056	320.8	327.4
2042	79.6	134.5	2057	151.7	151.7
2043	106.0	156.5	2058	245.0	249.6
2044	122.4	213.3	2059	131.8	135.1
2045	140.6	200.0	2060	148.8	189.0
2046	126.0	138.2	2061	204.6	242.2
2047	140.6	173.9	2062	153.6	211.7
2048	137.8	140.1	2063	98.5	121.1
2049	116.9	143.9	2064	82.6	177.3
2050	130.6	199.4	2065	145.9	209.1



(a)



(b)

Figure 5. Frequency distribution of annual maximum (a) 24-hr and (b) 48-hr precipitation in Agusan del Norte for 2020 climate scenario (2006-2035).

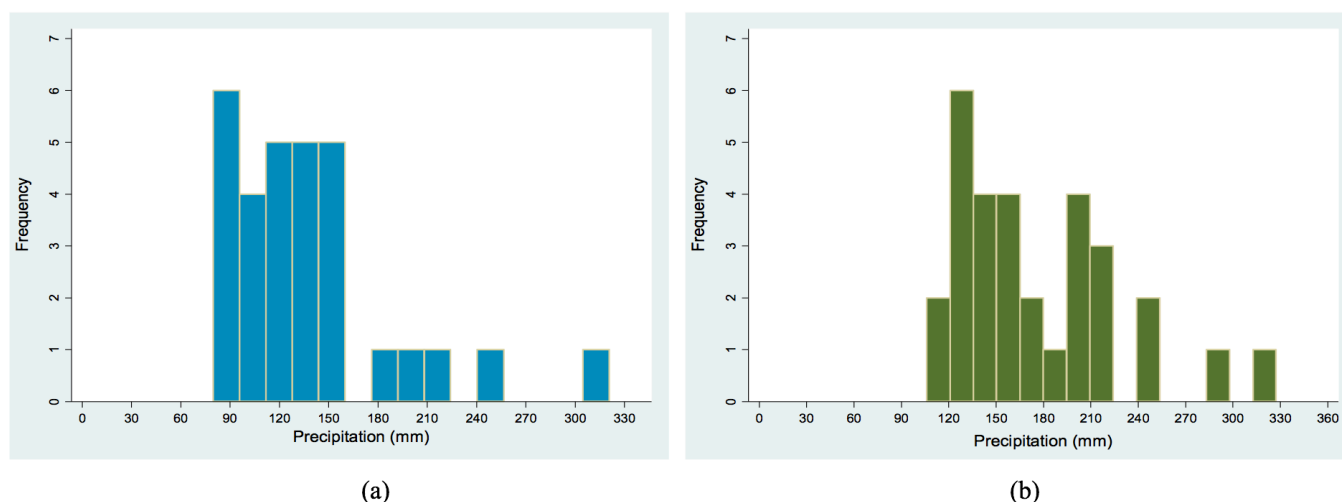


Figure 6. Frequency distribution of annual maximum (a) 24-hr and (b) 48-hr precipitation in Agusan del Norte for 2050 climate scenario (2036-2065).

Climate Scenario 2080 (2066-2095)

The magnitude and frequency distribution of the downscaled annual 24-hr and 48-hr maximum precipitation for 2080 climate scenario are shown in Table 7 and Figure 7, respectively. It can be seen that more extreme events are projected to occur. For this period, annual daily precipitation magnitude could range from 70 mm to 350 mm. If storm events last for 48 hours, they are projected to have up to 360 mm magnitude of rainfall. More concrete adaptation measures against the adverse impacts of the storm and/or flooding are required.

It can be observed that annual maximum precipitation projections from these models point to higher magnitudes compared to previous climate scenarios, affirming the existing studies about climate change projections in the Philippines (DOST-PAGASA, 2011).

Table 7. Annual maximum (max.) 24-hr and 48-hr precipitation values (mm) in Agusan del Norte for 2080 climate scenario (2066-2095).

Year	24-hr max. (mm)	48-hr max. (mm)	Year	24-hr max. (mm)	48-hr max. (mm)
2066	151.5	163.5	2081	185.3	256.5
2067	101.7	110.7	2082	115.7	115.7
2068	135.7	203.3	2083	177.3	189.4
2069	83.9	122.4	2084	123.2	146.1
2070	317.3	361.8	2085	88.7	143.4
2071	202.4	213.3	2086	210.6	230.3
2072	205.0	249.3	2087	83.8	95.6
2073	107.7	134.6	2088	239.2	362.0
2074	174.0	186.2	2089	130.0	196.5
2075	169.5	169.5	2090	221.0	327.1
2076	147.9	165.7	2091	120.3	124.2
2077	180.8	192.1	2092	120.6	227.4
2078	187.5	219.4	2093	118.2	153.2
2079	67.3	122.1	2094	346.9	346.9
2080	142.4	169.7	2095	89.7	106.3

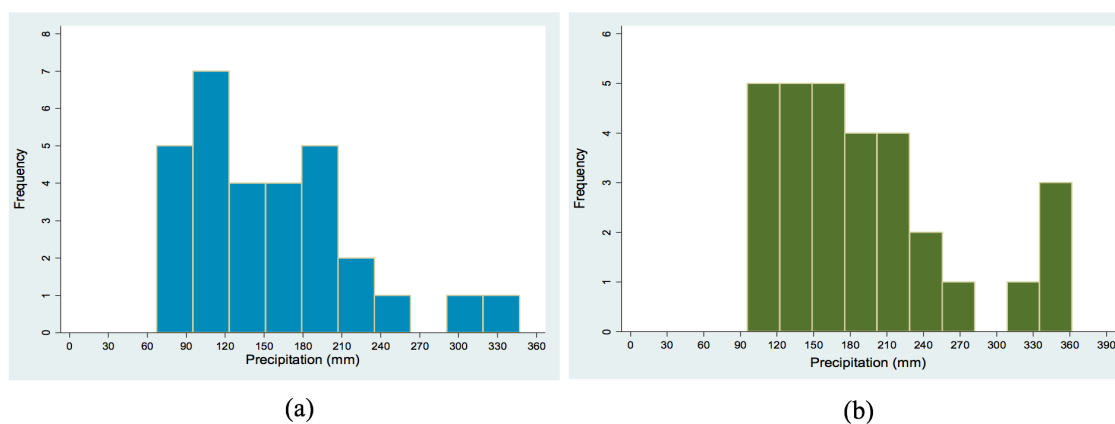


Figure 7. Frequency distribution of annual maximum (a) 24-hr and (b) 48-hr precipitation in Agusan del Norte for 2080 climate scenario (2066-2095).

Table 8. Seasonal rainfall change (in %) of different storm durations in Agusan del Norte in 2020 (2006-2035), 2050 (2036-2065) and 2080 (2066-2095)

Season	24-hr Duration				48-hr Duration			
	Observed Rainfall (mm) (1981-2003)	2020	2050	2080	Observed Rainfall (mm) (1981-2003)	2020	2050	2080
		% change				(% change)		
DJF	761.8	18.2	19.5	51.9	761.8	17.8	18.6	51.3
MAM	364.9	10.3	15.3	34.0	364.9	10.4	15.9	34.3
JJA	410.1	-3.8	11.0	20.3	410.1	-3.9	11.0	19.7
SON	527.1	7.3	6.4	15.3	527.1	7.9	7.2	16.4

Note: DJF (December-January-February); MAM (March-April-May); JJA (June-July- August); SON (September-October-November)

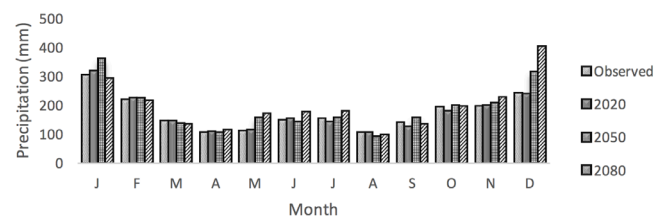
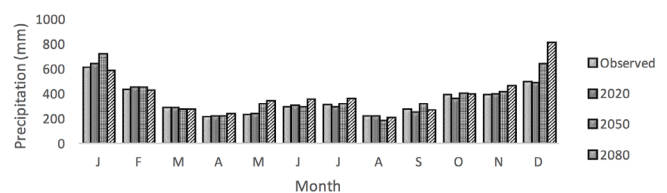
Comparison of Observed and Downscaled Data

Table 8 indicates the seasonal rainfall change (in %) of 24-hr and 48-hr storm durations in Agusan del Norte for future climate scenarios. It can be noticed that there is a projected increasing trend of precipitation magnitude in all seasons of future climates for 24-hr storm duration, except for the June-July-August (JJA) season in 2020 where there is a decreasing precipitation magnitude by about 3.8%. However, there is projected increase by about 11.0% and 20.3% in 2050 and 2080, respectively. In general, extreme storm events that could last for a day or 24 hours are projected to increase in the future.

Precipitation magnitude is expected to increase in the future, consistently among all scenarios and at different seasons with storm duration of 48 hours. Increasing precipitation magnitudes are projected during DJF season by about 17.8%, 18.6%, and 51.3% in 2020, 2050, and 2080, respectively. An increase of rainfall magnitude is seen during MAM season by about 10.4% in 2020, 15.9% in 2050, and 34.3% in 2080. A decreasing precipitation magnitude by about 3.9% is projected in 2020 during JJA season. This is projected to increase by about 11% and 19.7% in 2050 and 2080, respectively. Lastly, an increasing precipitation magnitude is projected during SON season by about 7.9%, 7.2%, and 16.4% in 2020, 2050, and 2080, respectively. These results imply that more intense and more frequent extreme events are expected to occur in the future.

From previous sections, it can be noticed that the higher frequency of maximum rainfall is toward higher magnitudes. Thus, the province is projected to experience more extreme rainfall events in the future. Figures 8 and 9 show the monthly total precipitation of Agusan del Norte across different climate scenarios according to a 24-hr and 48-hr durations of rainfall, respectively. For climate scenario 2020, an increasing magnitude of rainfall is projected for the months of January, February, April to June, and November. For climate scenario 2050, the months of January, February, April, May, July, and September to

December are anticipated to have the increasing intensity of rainfall. The months of April to July and October to December are projected to have an increasing magnitude of rainfall for climate scenario 2080.

**Figure 8.** Monthly total 24-hr maximum precipitation values in Agusan del Norte across different climate scenarios.**Figure 9.** Monthly total 48-hr maximum precipitation values in Agusan del Norte across different climate scenarios.

Conclusion and Recommendations

Through statistical downscaling technique, future precipitation centered on 2020 (2006-2035), 2050 (2036-2065), and 2080 (2066-2095) under A1B climate scenario were derived. The technique is more efficient and does not require intensive computing skills. Statistical downscaling involves selection of global scale atmospheric predictors that have significant relationship with the local climate variable. Model calibration and validation was done to

construct and validate the downscaling model given the daily precipitation data in the province and the outputs of NCEP A1B scenario. The validated model was used along with the output of CGCM3 to simulate future local climate data in the province.

In 2020, maximum precipitation is expected to reach up to 280 mm within a 24-hr duration of rain, and is expected to rise up to 320 mm if a storm would last for 48 hours. In 2050, projections showed that maximum precipitation could reach up to 320 mm and 330 mm of rainfall within 24-hr and 48-hr storm durations, respectively. In 2080, it is projected that the province will experience extreme rains with the magnitude of 70 mm to 350 mm within 24-hr storm duration and up to 360 mm if a storm will last for 48 hours.

Given the scope and limitations of the study, the same technique can still be employed for the province using the updated and new GCMs which will perform better than CGCM3. Also, four new greenhouse gas concentrations trajectories through representative concentration pathways (RCPs) have been presented by IPCC in their Fifth Assessment Report (AR5) (IPCC, 2014). It supersedes the emission scenarios considered in this study. These RCPs are used to describe four possible climate futures which depend on how much greenhouse gases are emitted in the years to come. Thus, projections of future climate in the province can also be simulated on the basis of these pathways.

Downscaled data for future precipitation scenarios are essential information for the local government unit of Agusan del Norte and for other agencies to conduct local studies such as vulnerability assessment and hydrologic modeling to understand hydrologic processes of some bodies of water in the area. This information is also an important input in updating the disaster risk reduction management plan of the province, and can be a basis for the formulation of suitable policies and programs addressing the climate conditions in the area.

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The role of traditional ecological knowledge in the disaster risk management strategies of island communities in Cat Hai, Vietnam

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Abstract

The very real threat of climate change requires effective disaster risk management (DRM), especially in highly vulnerable ecosystems such as island communities. Past disaster experiences in different parts of the world have revealed the importance of integrating traditional ecological knowledge (TEK) with scientific findings in managing disaster risk. Hence, this study assessed the role of TEK in the DRM strategies of communities in Cat Hai Island, Vietnam. Participatory Rural Appraisal techniques such as key informant interviews, household survey, and focus group discussion were used to collect primary data. The survey was administered to 50 residents of three communes in Cat Hai Town. Results showed that the respondents use their TEK together with information from the mass media in predicting, preparing for and coping with the impacts of weather-related disasters such as floods and storms. The results of this study could be used in creating an effective community-based DRM program for the above mentioned communities. The lessons from this study could serve as a reference and guide for other coastal communities that are vulnerable to weather-related disasters and climate change.

Keywords: traditional ecological knowledge · community perception · disaster risk management · climate-related disaster · Cat Hai Island

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Introduction

The frequency and intensity of extreme events are going to change as climate change affects the environment and systems in which they occur (Banholzer, Kossin, & Donner 2014). For example, the increased moisture content in the atmosphere, due to increased greenhouse gases in the air, could fuel more extreme precipitation events (Kunkel et al., 2013). Over the last twenty years, water-related disasters have caused over 600,000 deaths and affected more than 4.1 billion people across the world (Centre for Research on the Epidemiology of Disasters [CRED] & United Nations Office for Disaster Risk Reduction [UNISDR], 2015). Because of this, the impacts of climate change are becoming more pronounced.

The need to strengthen disaster risk management (DRM) is more evident now than ever. Several studies argued that science-based DRM could be improved and communicated effectively by integrating it with local knowledge since the latter is readily acceptable to the community (Ikeda, Narama, & Gyalson, 2016). Because of this, the local, traditional, and indigenous knowledge are important in reducing disaster risk (International Strategy for Disaster Reduction [ISDR], 2005, 2008a, 2008b; Kelman, 2010).

The terms “local”, “traditional”, and “indigenous” are sometimes differentiated in disaster management and climate change adaptation studies (Etkin & Stefanovic, 2005; Lebel, 2013; Codjoe, Owusu, & Burkett, 2014), and at other times considered similar or overlapping in others (Tearfund, 2008; Mercer, Kelman, Suchet-Pearson, & Lloyd, 2009; Kelman, Mercer, & Gaillard, 2012; Hiwasaki, Luna, Syamsidik, & Shaw, 2014). Although both indigenous and traditional knowledge are passed down from generation to generation (Materer, Valdivia, & Gilles, 2002; Hiwasaki et al., 2014), indigenous knowledge is only held by people who identify themselves as indigenous (Lebel, 2013). It encompasses knowledge about cultural traditions and worldviews of the indigenous people, whereas traditional knowledge indicates knowledge about the economic, political, and spiritual relationships with the land of local people (Brockman & Legat, 1995 as cited in Brockman, Masuzumi, & Augustine, 1997).

Traditional ecological knowledge (TEK) is identified as a cumulative body of knowledge, practices, and beliefs that is evolving by adaptive processes through generations, and is about the relationship of living beings (including humans) with other individuals and with their environment (Berkes, Colding, & Folke, 2000). Scholars find it difficult to distinguish among these three terms because their definitions are abstract (McGregor, 2006). The similarity of these terms is that they are defined by many generations who not only managed to survive but also live in harmony under harsh conditions of nature (Hiebert & Van Rees, 1998). Therefore, in this paper, the term TEK is used to refer to the environmental knowledge that was derived from experience and traditions (Greneir, 1998; Leonard, Parsons, Olawsky, & Kofod, 2013) of a non-indigenous rural community in Cat Hai Island, Vietnam.

In recent years, weather-related hazards in Vietnam are becoming more severe in terms of magnitude, frequency, and volatility (Huy & Shaw, 2010). During a period of twenty years from 1993 to 2012, Vietnam was exposed to 213 weather-related disasters and was considered as one of the six worst affected countries by climate change (Kreft & Eckstein, 2013). Moreover, majority of its population are residing in coastal areas and small islands making them more vulnerable to the impacts of weather-related hazards, such as storms and floods (Dat & Thu, 2012; Hiwasaki, Luna, Syamsidi, & Marcal, 2015). To cope with these events, the country established its DRM strategy. The TEK or indigenous knowledge was mentioned in Decision 2139 QD-ttg of the Vietnamese Prime Minister (2011) approving the national strategy for climate change. However, TEK was not captured in the regional or provincial strategies. Meanwhile, the locals in coastal areas have a rich culture and traditional knowledge, which they use to adapt to the changing environment (Thinh, 2010) and to mitigate disaster risk (ISDR, 2008b; United Nations Educational, Scientific and Cultural Organization [UNESCO], 2014). Hence, this paper assessed the potential role of TEK in improving the island's DRM strategy, as well as the present coping strategies to flood and storms employed by the community. Based on the research results, this paper recommended methods to preserve valuable TEK for use in DRM.

Materials and Methods

Study Area

The study was conducted in Cat Hai Island, one of the two main islands of Cai Hat district in Hai Phong province in North Vietnam. It is a flat sand island covering a total land area of about 40 km². The island is 24 kms away from the center of Hai Phong City and is located between Cat Ba Island and Do Son Peninsula. Its climate is characterized by two distinct seasons: cold and dry northeastern monsoons (winter) from November to April, and cool and fresh southeastern monsoons (summer) from May to October. Its average annual rainfall ranges from 1,600 mm to 1,800 mm, while the average monthly temperature varies from 20 to 23°C. The island is considered as one of the most vulnerable areas to storm in Vietnam with 28 percent of the storms in the country crossing the island (Thung, 2014).

Cat Hai Town, located on the northeast side of the island, suffers most from the impacts of storms, waves, and floods (Thung, 2014; Cat Hai Town People's Committee, 2015). With six communes, it covers 4.92 km² land area, wherein 0.023 km² is classified as forestland. In 2015, the town had a population of 6,700 belonging to 1,670 households. Most of the residents rely on fishing, aquaculture, and seafood processing (salt making, fish sauce making) to earn a living. The town has a high literacy rate since most of the families send their children to school. According to reports of Cat Hai Town People's Committee (2013, 2014, 2015), the three communes in Cat Hai namely, Tien Loc, Hai Loc, and Dong Luong were

ranked as the most vulnerable to storms and floods. Their flood level and economic damage are always higher than other communes. In these areas, most of the settlements are either located in the lowest regions of the island or alongside the embankment (Cat Hai Town People's Committee, 2015).

Data Collection and Analysis

Primary data was collected using Participatory Rural Appraisal (PRA) methods such as key informant interviews (KII), household survey, and focus group discussion (FGD). PRA method is effective at the community level because communities usually respond well and openly during the conduct of PRA (Ramasubramanian, Seeralan, & Sekar, 2010). It is an effective tool in capturing the community perception (Cornwall & Pratt, 2011). The study used PRA to elicit the community perception on the immediate disaster impacts and disaster risk management practices in Cat Hai Island, as well as their TEK in storm and flood prediction.

The household survey was written and recorded in Vietnamese language and conducted between the 26th and 30th of April 2015. It determined the experiences and perception of households on disaster risk. Because the location of the target respondents was pre-identified through KII, the study employed purposive sampling to guarantee that the respondents could provide valuable and relevant information.

A total of 50 households were surveyed, wherein 25 came from Tien Loc Commune while 15 and 10 were residents of Hai Loc and Don Luong Communes, respectively (Table 1). The distribution of respondents was determined based on the level of vulnerability of the commune, with the highest sample size allocated to the most vulnerable area (Tien Loc) (Cat Hai Town People's Committee, 2015, 2014, 2013). Households

present during the time of fieldwork were included in the survey. The survey questionnaire with 41 questions was designed to capture the socio-economic characteristics of the respondents and their perception on the three main topics: (1) local perception on DRM, (2) role of TEK in DRM (TEK on storm and flood prediction; local practices to cope with flood and storm; and integrating TEK in DRM), and (3) measures to preserve and improve the contribution of TEK in DRM.

An FGD was conducted to validate the survey results and to gather information on the DRM of the island. Authorities in Cat Hai Town (representatives of Commune Committee for Natural Disaster Prevention and Control and Search and Rescue [CCNDPC and S&R], Cat Hai Town People's Committee, Cat Hai Town Military Affairs, and Cat Hai Town Veteran Affairs) were invited to participate in the activity.

Results and Discussion

Local Perception on Disaster Risk Management

In this study, weather-related hazards or disasters pertained to storms and floods since these were the most common hazards experienced in the study area. All of the household survey respondents observed an increased intensity and magnitude of recent storms. This observation was consistent with the results of the FGD and findings of other scientific studies in Vietnam (Huy & Shaw, 2010). All of the interviewees claimed that they had knowledge of the disaster risks including storm surge and flooding in their vicinity.

The FGD results indicated that the provincial government was funding the construction of a dyke and drainage system and mangrove protection activities. Dyke construction was noted in several studies as one of the national government's main strategy in reducing the impacts of floods and storms (Phuc, 2011; Reynaud, Aurbert, & Nguyen, 2013; Casse, Milhoj, & Nguyen, 2015), with mangrove protection activities mainly available in Cat Ba Island – the other island of Cat Hai district and the center of Cat Ba National Park. Every year, the authorities at the provincial level take the main responsibility of repairing and strengthening the dyke and drainage systems in Cat Hai Island. On the other hand, the 'Four on-the-spot motto', which has been documented in legal documents since 2006 by Vietnam's Government (Decree No. 8/2006 / ND-CP), was the main DRM strategy employed by the locals of Cat Hai Island. The program name was coined from its four objectives—leadership on-the-spot, human resources on-the-spot, means and materials on-the-spot, and logistics on-the-spot. The implementation of this program in Vietnam has been a successful example of community-based disaster risk reduction and management strategy (Shaw, 2012).

For the island, an annual budget of 30 million VND (~1,388 USD¹)

¹ USD=21,610 VND (Vietcombank, April 2015)

Table 1. Socio-economic characteristics of the respondents in Cat Hai Island, 2015

Characteristics		Tien Loc Commune n=25	Hai Lo Commune n=15	Don Luong Commune n=10
Age (years)				
Mean		47	49	53
Range		14-60	40-57	37-70
Annual gross income per household				
Mean*	USD	2,108	1,646	1,902
*1 USD= 21,610 VND (Vietcombank, April 2015)	VND	45.56 million	35.56 million	41.11 million
Primary source of livelihood (%)				
Farming		4	0	40
Fishing		32	60	30
Non-resource –based		63	40	30
Average number of household members		4	5	4

was regularly allocated for activities comprising both proactive and reactive measures to reduce disaster risk at commune level, following the Four on-the-spot motto. Proactive strategies mainly focused on early warning mechanisms and disaster risk prevention activities prior to storm landfall, such as strengthening of houses, anchoring of boats, cutting down and trimming of trees, and early evacuation of vulnerable people like elders, pregnant women, and children (Cat Hai Town People's Committee, 2015).

The role of the mangrove and dyke drainage systems on DRM in this island is still an ongoing debate. The ability of mangroves to protect coastal communities against natural hazards such as storms, tsunamis, and coastal erosion has been widely promoted around the world (Spalding, McIvor, Tonneijck, Tol, & van Eijk, 2014). However, in this island, survey results revealed that there seemed to be some misconception about the role of mangroves in disaster risk reduction since 66% of the respondents believed that mangroves could not reduce the impacts of flood and storms. Most (94%) of the mangrove area in this island has been replaced with infrastructures (dyke system, road, etc.) and shrimp farms.

In comparison, 70% of the interviewees believed in the reliability of the dyke system around the island in protecting them from impacts of storms. All respondents believed in the reliability of the new two-kilometer concrete dyke system from K0+000 (Got Berth) to K3+094 (Cai Vo). It was upgraded to withstand even level 10 storms, but interviewees were doubtful of the remaining 20.6 km dyke system of the island, which was still made of stones, thinking it could easily be damaged by storms and needed repairs almost every year.

Majority (74%) of the survey respondents perceived that their present drainage systems had low draining capacity, increasing their exposure to flood, particularly in low-lying communes like Hai Loc and Tien Loc. Meanwhile, 34% of interviewees noted that the newly built dyke replacing the mangroves system slowed down the flood receding rate. Some people shared that it took about two to four hours longer than in the

past for floods to recede in Tien Loc and Hai Loc communes. Some interviewees further explained that in the past, when they used mangrove systems and/or the stone dyke system to protect them from storms, flood could recede via the drainage systems and through the holes in the stone dyke. After the authorities upgraded the dyke systems without the drainage systems, the flood could not recede through the new concrete dyke.

Role of Traditional Ecological Knowledge in Disaster Risk Management

Traditional Ecological Knowledge on Storm and Flood Prediction

Several studies have confirmed the role of TEK in the prediction of natural hazards such as floods and storms. TEK of this kind was developed through detailed observation of the environment including the behavior of animals, changes in morphology and physiology of plants, cloud patterns, and the appearance of moon and other celestial bodies (Woodley, 1991 as cited in Materer et al., 2002; Enock, 2013; Rivero-Romero, Moreno-Calles, Casas, Castillo, & Camuo-Guerro, 2016). Communities in Zimbabwe predicted natural hazards by observing the behavior of animals, insects, and plants (Kihupi et al., 2002; Mhita, 2006; Huy & Shaw, 2008; Enock, 2013; Hiwasaki et al., 2015). Storm prediction through observing cloud direction was also documented in some studies with the appearance of cumulonimbus clouds signalling heavy rainfall or storm (Barry & Chorley, 1998; Hiwasaki et al., 2015).

Similar to these studies, the local people in Cat Hai have been predicting the occurrence of storms and floods by using TEK and observing their environment. Most of them could predict these events by simply looking at the changes in the sky, plant growth, and animal behavior (Table 2). About 60% of the survey respondents, all of whom were fisher folk, said that they were knowledgeable in the traditional practices of predicting storm and flood. They explained that these beliefs were already embedded in their livelihood because their

Table 2. Traditional ecological knowledge of the respondents in predicting storm

Signs	Belief	Number of users* (%) n = 50	Number of holders* (%) n=50
Sky Cloud	There will be a storm once a cumulonimbus cloud (dense towering vertical cloud) appeared. If the clouds are moving from the sea to the land, the island will not be affected. If the direction of the clouds is from inland to sea, the storm will definitely hit the island. If clouds are moving fast, the storm will also move fast.	28	44
Lightning and thunder	If there is rain, thunder, and lightning above the sea, incoming storm will be very violent (Ancient local people refer to it as "Bão đồ đĩnh").	24	74

(Continued) Table 2. Traditional ecological knowledge of the respondents in predicting storm

Signs	Belief	Number of users* (%) n = 50	Number of holders* (%) n=50
Rainbow	A storm will come shortly once a rainbow appeared in the east.	20	64
Plants	If bamboo shoots grow toward the land instead of ponds, lakes, and rivers, it will be a stormy year.	12	36
	A strong storm is possible if the yield of Longan (<i>Dimocarpus longan</i>) fruit is more than the usual.	8	30
Animals			
Insects	There will be a storm once the ants move their eggs into elevated areas and termites leave their nest.	70	84
Marine Species	A strong storm is coming if many mullets appeared on the sea surface.	28	74

*Users are those who actually use the information to predict the onset of disasters, while holders are those who have mastered how to interpret the signs

ancestors, who were also fisher folk, used them for centuries. However, these traditional practices are becoming unpopular at the study site in recent years because of modern technology. Despite knowing about these practices, 90% of the sampled households indicated that they relied mostly on weather updates from the agency of hydro-meteorological forecasting. This was manifested in the difference between the number of holders of the TEK (those who have mastered how to interpret signs) and the number of users (those who actually use that information to predict the onset of disasters) (Table 2). FGD participants also noted that most of the local inhabitants, especially the youth, relied on the more accurate weather forecasting that reached them through the mass media. The elderly and fisher folk combined both TEK and updates from the media to determine weather forecast. This result is similar to several studies in other countries (Rivero-Romero et al., 2016).

On the other hand, all respondents were still using their TEK and experience in terms of flood prediction. The community was able to preserve their knowledge on the tide calendar, which is their main tool for predicting flood and determining the best time to catch fish (This knowledge is similar to TEK of other coastal regions in Vietnam). Locals predicted the level of the tide according to the lunar calendar. If a storm happened on a high tide day, the level of flooding would be higher than normal. This knowledge was passed on from a long history of fishing tradition. Although all of the respondents were familiar with the tide calendar, only 20% (mainly fisher folk and elders) mastered the flood predictions; hence, other residents depended on them for this kind of information. The respondents perceived that the information generated from the tide calendar was relatively precise.

Local Practices to Cope with Flood and Storm

All of the respondents have developed coping strategies using their experience and TEK. Table 3 summarizes these strategies, classified into proactive strategies (done before the

Table 3. Local practices to cope with flood and storm

Coping Strategies	Respondents (%)
Proactive	
Installing small concrete walls at the bottom of the doors or around the water tanks and wells to block flood water	34
Renovating house	18
Moving elderly and children to relatives' houses or public shelters	68
Moving properties to elevated areas of the house or to set up scaffolds and float	94
Reactive	
Relying on the immediate and extended families and other community networks	100
Repairing houses and clearing debris from the houses immediately after the flood	100
Travelling by boats in Tien Loc commune	40

natural hazard occurs) and reactive strategies (done after). The most commonly practiced proactive strategies mentioned by survey respondents are moving their properties to elevated areas one to two days before storms (94%) and evacuating their elders and children either to their relatives' houses or to public shelters, like schools and hospitals, a couple of days before the storm (68%). Combined with weather forecast data, TEK helped habitants to predict when flooding would occur. From this, the locals could proactively come up with short-term strategies (two to three days before a storm occurs) to deal with flood (Young, 1998). Moreover, 34% of the respondents installed small concrete walls at the bottom of their doors or

around their water tanks and wells to block out floodwater. Interestingly, five interviewees responded that TEK sometimes helped them to predict the possibility of storms, which could cause flood for a few months (in the average term), by looking at signs of plants. As a response, they built small concrete walls at the bottom of their doors or around their water tanks and wells months before the storm season. In addition, some households elevated their floors from an average of 1.5 to 2.0 m to avoid flood inundation. This strategy of elevating houses was also documented as one of the coping strategies to flood impacts in central Vietnam (Reynaud et al., 2013).

After the storm and flood, all of the respondents relied on their social networks to easily cope with the losses and damages. They claimed that disasters have strengthened the social networks in their community. In addition, all of the respondents cited that these events temporarily disrupted the transportation system for two to three days both in and out of the island. Ferries and boats could not navigate around the area. Even the locals, especially those in Tien Loc commune, the lowest area of the island, could not travel across the island by land because roads were mostly inundated. They had to use floats or boats to travel from one place to another. About 40% of total respondents (20 of the 25 interviewees in Tien Loc commune) noted that they traveled by boats for half a day to as long as two days after a flood, noting that the newly built dyke had reduced the drainage rate.

Integrating Traditional Ecological Knowledge in Disaster Risk Management

The FGD and KII participants emphasized the importance of integrating TEK into the current DRM of Cat Hai Island. Current practices showed that the level of preparation before the storm was mostly based on the early warning information from the hydromet agencies. The weather-forecasting programs try to provide the most accurate forecasts in terms of storm track, wind direction, and storm level. However, there are uncertainties in the climate system that affect the accuracy of the storm forecasts. Moreover, the flood risk in the study area is affected by the tide level. At times, although the storm level is low, the flooding level remains high due to the high tide level. Hence, disaster preparation activities in Cat Hai are sometimes perceived to be ineffective when they have been based on weather-forecasting information alone.

Accounts from the interview and FGD noted that there were instances when the local authorities and communities did not prepare as there were no forecasted storms, but due to high-tide level, their areas were seriously flooded. Only those households which used both TEK (the tide calendar) and information from the local authorities were able to proactively mitigate the impact of extreme events, especially flooding, by building small concrete walls at the bottom of the doors and moving their furniture to higher places. Thus, some FGD and KII participants emphasized that the current DRM of Cat Hai Island could still be improved through better TEK integration.

This integrated approach has been suggested in several studies as it enables the communities to formulate and implement the most appropriate coping strategies to weather-related hazards (Lucio, 1999; Krishnamurthy, Fisher, & Johnson, 2011; Hiwasaki et al., 2014). Several studies recommended ways that could be used for that purpose (Botterill & Wilhite, 2005; Baumwoll, 2008; Tran, Shaw, Chantry, & Norton, 2009; Krishnamurthy et al., 2011; Gaillard & Mercer, 2013). For instance, the locals could use TEK as part of the early warning system such as anticipating the intensity of storms and making necessary preparations few months before the storm season to reduce storm and flood impacts. Similarly, if the signs of storms and flood prediction are recognized several days before those events occur, short-term strategies can be formulated to cope with disaster risk.

Given the importance of TEK, governments, institutions, and/or networks need to strengthen and encourage cross-disciplinary TEK research (Etkin & Stefanovic, 2005) and TEK documentation. FGD and KII participants noted that since TEK presentation or transfer could be in the form of storytelling and idioms attached directly to the local livelihoods and their environment, island inhabitants, especially children, could easily acquire knowledge on DRM through TEK or combination of TEK and scientific knowledge rather than relying on scientific knowledge alone. Therefore, disaster managers should use both TEK and scientific knowledge to enhance local awareness and capacity to cope with weather-related disasters. For instance, governments and institutes could provide the scientific basis of TEK (Enock, 2013) and collect TEK information via open discussion with the locals. They can work with the locals in documenting the TEK and information on disaster risks, then transform them into a mapping tool such as through Geographic Information System (GIS). This can be used in mobilizing available human and technical resources and also in strengthening the partnership between local communities and institutions (Tran et al., 2009). The locals could also be encouraged to proactively be involved in DRM activities.

Measures to Preserve and Improve the Traditional Ecological Knowledge in DRM

At the local level, people should preserve TEK. The FGD participants enumerated three main strategies in preserving TEK: (1) identifying local leaders who could promote the integrated TEK and scientific findings, (2) developing oral narratives, and (3) using the extended family model (“mô hình dòng họ”).

Ikeda et al. (2016) emphasized the importance of determining and developing local leaders who could promote both local and scientific knowledge in DRM. The FGD participants believed that the elderly people were in the position to do that as they could attest to the effectiveness of TEK in reducing disaster risk. At the same time, the TEK could be presented through oral narratives in the form of storytelling,

poems, idioms, and cultural and art performance, among others. All the respondents of the survey also supported this recommendation. The importance of oral traditions has been established in several disaster-management studies (Syafwina, 2014; Ikeda et al., 2016). Lastly, FGD participants and 74% of the respondents argued that the extended family model could also be used to disseminate TEK between clans effectively. Through this method, TEK can be documented in a written report by the locals (e.g., leaders of communes, families). Then, reports can be passed on to the next generation of extended families and communities who could also revise or improve its application via oral narratives. The extended family model method could be effective in reducing disaster risk since increasing human interaction and communication between family generations are important in enhancing community-based disaster prevention strategies (Nakamura, Umeki, & Kato, 2016).

Conclusion and Recommendation

The residents of Cat Hai Island, especially the elders and fisher folk, were able to preserve their TEK on storm and flood prediction. This body of knowledge has been passed on from generation to generation by word of mouth. They were able to predict storms by observing the changes in the sky (i.e., clouds, lightning and thunder, rainbow), plant growth, and animal behavior. In recent years, they have been relying both on their TEK and on weather forecasts delivered through the mass media. When it comes to flood prediction, they were still using their TEK of the tide calendar. Although TEK was widely used by the residents, currently, the young generation and local authorities in the island are likely to omit TEK in their DRM strategy. The local authority in the island, in terms of DRM strategy, is mainly focused on strengthening infrastructure (dyke and drainage systems).

This study concludes that the residents of Cat Hai Island have a rich body of TEK that could be used in improving the island's current DRM program. Through an open discussion with the local people, the disaster managers could understand and document disaster risk and TEK in the island. Using the documented TEK, they could establish better medium- and short-term strategies to reduce disaster impacts in the island. However, this study also recognized the need to evaluate the TEK and determine which of them could be integrated with science-based DRM strategies.

Having demonstrated the potential role of TEK in DRM, this study suggests integrating relevant TEK in the DRM activities of Cat Hai Island such as in early warning system and awareness raising activities so the community can better prepare in addressing the impacts of future storms and floods. The integration of TEK and DRM activities could lead to an effective community-based DRM program. Both the government and local people should preserve, document and improve TEK. The documented TEK in Cat Hai Island

on flood and storm prediction and the lessons to integrate TEK and DRM activities in the island could also be applied to reduce disaster risks in other coastal areas not only in Vietnam but in other parts of the world.

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Tourism Industry Financing of Climate Change Adaptation: Exploring the Potential in Small Island Developing States

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Abstract

In many small island developing states (SIDS), tourism is a principal driver of the economy and of infrastructure development. The SIDS' tourism sector is, however, threatened by climate change impacts, which will likely incur high costs for climate change adaptation (CCA). Discussions are starting about who should pay for the costs of adapting to climate change, especially the balance amongst sectors such as between governments and the tourism industry. Through the perceptions of selected industry stakeholders, this study explores the potential of the tourism industry in SIDS in financing its own CCA. Fiscal and political mechanisms were examined, such as adaptation taxes and levies, adaptation funds, building regulations, and risk transference. The study's exploratory method combines nine in-depth key stakeholder interviews from various SIDS and an extensive literature review to develop a schematic of suggested mechanisms. The results reveal a high overall potential for the tourism industry funding its CCA, but with significant challenges in realizing this potential. Consumer expectations and demands, governmental hesitation in creating perceived investment barriers, and assumptions about cost effectiveness could undermine steps moving forward. Varying incentive structures, the sector's price sensitivity, and the differing abilities of tourism industry stakeholders to adapt are factors suggesting that government frameworks are needed to ensure effective and substantive action.

Keywords: Climate change · adaptation · climate finance · islands · SIDS · small island developing states

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Introduction

Small Island Developing States or SIDS are several countries said to have similar development challenges and opportunities (United Nations Framework Convention on Climate Change [UNFCCC], 2007). They are particularly vulnerable to climate change, especially to impacts such as sea-level rise, changing frequencies and intensities of weather extremes, coastal flooding and erosion, and ocean acidification (UNFCCC, 2015; Nurse et al., 2014); but they also display significant resilience to challenges faced (Gaillard, 2007; Lewis, 1999), albeit with significant financial burden on their governments and economic sectors to adapt to and recover from climate change impacts.

To help cope with these costs, USD 100 billion of international climate finance was pledged annually from 2020 onwards to support developing countries in tackling climate change impacts, with SIDS prioritized as recipients (UNFCCC, 2015). The USD 100 billion is supposed to come from both private and public sources, yet the private sector's involvement remains unclear and creates challenges (United Nations Environmental Programme [UNEP], 2016; Dzebo & Pauw, 2014). Available data on private sector contributions to adaptation is sparse (Brown et al., 2015; Buchner, Trabacchi, Mazza, Abramskiehn, & Wang, 2015). Buchner et al. (2015) estimated an overall contribution by the private sector of USD 245 billion in 2014 for dealing with climate change.

Many SIDS are experiencing climate change impacts and need financial resources to adapt (Intergovernmental Panel on Climate Change [IPCC], 2014a). Climate change adaptation (CCA) is "[t]he process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities" (IPCC, 2014b, p. 118). CCA finance is understood as comprising all financial resources that are mobilised, pledged, or spent on adaptation.

One of the main economic sectors for many SIDS (Connell, 2013; United Nations World Tourism Organization [UNWTO], 2012; Scheyvens & Momsen, 2008) is tourism, which is considered as one of the biggest global industries (UNWTO, 2016). SIDS governments frequently support the tourism industry financially, including paying for development, due to its assumed benefits such as generating employment, fostering development, generating tax revenues, and justifying the value of protecting natural resources. But climate change is projected to exacerbate existing development challenges, such as fresh water supply and infrastructure resilience to storms, indicating the need for the tourism industry to adapt (Scott, Hall, & Gössling, 2016; IPCC, 2014a; Scott, Gössling, & Hall, 2012; UNWTO, UNEP, & World Meteorological Organization [WMO], 2008). This setting leads to an inquiry whether it is the SIDS' governments or the tourism industry that should pay for all CCA initiatives in the tourism industry, or if these costs should be shared between them.

The SIDS tourism industry could be encouraged to support adaptation financing due to its dependency on SIDS' destination attributes and activities, such as beaches and diving. Other

concerns could also emerge, providing impetus for supporting adaptation financing. In some SIDS locations, tourists' use of water and energy is a concern or tackling eroding shorelines is priority. Consequently, multiple reasons might emerge, but the short-term thinking of some sector stakeholders needs to be considered, in that parts of the tourism industry might be seeking the quickest way of achieving maximum profit.

This paper explored the potential for involving the tourism industry in SIDS to fund its own CCA by examining views of potential roles which the industry could play.

SIDS in the Context of International Tourism and Climate Change

In many SIDS, the tourism industry generates a significant share of the country's gross domestic product (GDP). For example, tourism share was estimated at 76.8% of GDP in Palau in 2012 (Central Intelligence Agency [CIA], 2014), at 47.3% in Vanuatu in 2015 (World Travel and Tourism Council [WTTC], 2016b) and at 38.7% in Fiji in the same year (WTTC, 2016a). Tourism is often perceived as a key development option for SIDS, especially when exports face significant constraints due to high transportation costs, market entry barriers, and unfavourable trade agreements (UNWTO, 2012; Brau, Liberto, & Pigliaru, 2011; Bishop, 2010; Narayan, Narayan, Prasad, & Prasad, 2010; Croes, 2006). However, tourism markets are particularly vulnerable to sudden changes, such as from the global economy, perceptions of political unrest and violence, and media portrayals of adverse environmental impacts (Connell, 2013; Graci & Dodds, 2010). The impacts of specific events on visitor numbers can be short-lived, but structural or long-term changes, such as from climate change, can significantly alter a destination's perceived or actual functionality and appeal (Mahon, Becken, & Rennie, 2013; Narayan et al., 2010; Gössling, Bredberg, Randow, Sandstrom, & Svensson, 2006).

Projected climate change impacts on SIDS include changing patterns of weather extremes, water scarcity, biodiversity loss, sea-level rise, and ocean acidification (c.f. IPCC, 2014a; Gössling et al., 2012; Scott et al., 2012; Becken & Hay, 2007). Table 1 shows how such impacts can affect the tourism sector, especially through reputational risks, threatening the attractiveness of SIDS as tourist destinations or perceptions thereof (Shakeela & Becken, 2015; Mahon et al., 2013; Wright, 2013; Gössling et al., 2006). Ironically, the demand for this market segment, and government policies to support it, produces a pattern of coastal zone tourism development that can further increase the place's vulnerability to weather extremes (Juhász, Ho, Bender, & Fong, 2010; Allison, 1996).

Table 1. Illustrative impacts of climate change on tourism in SIDS (based on IPCC, 2014a; Scott et al., 2012; UNWTO et al., 2008)

Climate change effect	Tourism impacts	Tourism impacts
Sea-level rise	Coastal erosion, beach loss	Clearing coastal areas of vegetation,

Table 1 (Continued)

Climate change effect	Tourism impacts	Tourism impacts
Sea-level rise (Continued)		artificial beach nourishment
A changing storm regime	Damage to tourism facilities, increased insurance costs, business interruption	Developing tourism infrastructure in hazard-prone areas, poor quality of building design and materials, insufficient disaster risk reduction and disaster management
Biodiversity changes	Loss of natural attractions and species from destinations, especially for coral reefs	Pollution, poor waste and waste-water management, disturbance of animals in protected areas, reduction of and damage to natural habitats
Warmer temperatures	Heat stress for tourists, increased cooling costs, coral bleaching	Inadequate building design, reduction of tree cover and natural shading options

Private Sector Involvement in Climate Adaptation Finance

After the initial pledge to provide USD 100 billion annually by 2020, private sector involvement in adaptation finance was increasingly highlighted (UNEP, 2016; Pauw & Pegels, 2013; Atteridge, 2011). In this article, the term ‘private sector’ is primarily understood as any privately-owned enterprise. The private sector will likely have to adapt, and in many cases already adapts, to climate change through exploiting new business opportunities and managing climate-related risks (Pauw, 2015; Surminski, 2013). Tracking private finance in adaptation is a major challenge due to scarcity of information (Pauw, 2015; Agrawala et al., 2011).

Much investment in adaptation is not officially declared, tracked, or labelled as such, instead takes place through incremental changes and adjustments of infrastructure and responses to changing demand patterns (Christiansen, Ray, Smith, & Haites, 2012). Having little data does not mean an absence of adaptation investments. Case studies verify that adaptation and its financing take place on different levels, e.g., by small- and medium-sized enterprises (UNFCCC, 2014; Bradshaw, Dolan, & Smit, 2004; Qiu & Prato, 2012) and by large companies (UNFCCC, 2016; Kolk & Pinkse, 2005).

There was a proposal to raise USD 8 to 10 billion annually through an International Air Passenger Adaptation Levy (IAPAL) for financing adaptation in developing countries (Müller, 2008). In 2008, the UN’s group of Least Developed Countries proposed to include the IAPAL within the UNFCCC Bali Action Plan, but they did not succeed (Scott & Becken, 2010). The proposal shows that the tourism sector has some potential for becoming a major source of adaptation financing. Concerns were raised, however, about possible impacts of such a levy on global air travel dynamics and its consequences for tourism-dependent SIDS. Nevertheless, one investigation concluded that “the potential benefits of IAPAL for countries reliant on tourism are likely to outweigh the costs of slightly reduced tourist numbers” (Chambwera, Njewa, & Loga, n.d., p. 12), implying that the industry would not be harmed by such a levy and that industry supporting the levy would see an adequate return on investment.

In the end, the private sector “will expect the same return on their investment [‘risk premium’] in adaptation that is available from other investments with a similar risk profile” (Christiansen et al., 2012, p. 8). Uncertainties for tourism in SIDS include: (i) unclear magnitudes and time scales of regional and local climate change impacts; (ii) public policy changes and reliability; (iii) political instability; (iv) development of international tourism flows; (v) non-transparent and unreliable political systems; and (vi) limited ability and experience for diversifying risks amongst different economic sectors (Transparency International, 2016; Ackerman & Stanton, 2013; Buchner et al., 2013; Connell, 2013; Wong, de Lacy, & Jiang, 2007; Schelling, 2007). In other words, the largest uncertainties come from human responses to climate change rather than from climate change itself, which is a challenge for the private sector to respond to when many of the responses are government-led.

Methodology

This exploratory study is based on a mixed methods approach and brings together findings from the literature and a stakeholder approach comprising nine semi-structured, in-depth interviews. An initial literature review and analysis identified six mechanisms which are relevant and feasible for involving the tourism industry in financing its own adaptation. An in-depth literature review ensued.

In terms of the stakeholder approach and within the context of climate change uncertainties and how humanity might respond to the impacts, stakeholder theory can further enrich the understanding of the potential interest and perspectives of the tourism industry in financing its adaptation. A stakeholder is “any group or individual who can affect or is affected by the achievement or the organisation’s objective” (Freeman, 1984, p. 46). Stakeholder theory can be understood as “a theory of organizational management and ethics” exploring the interaction between a company and their stakeholders (Phillips, Freeman, & Wick, 2003, p. 480). A range of papers has debated

if the natural environment, and as a part of it climate change, could be considered as being a stakeholder, with some arguing for it (e.g., Haigh & Griffiths, 2009; Kolk & Pinkse, 2005; Starik, 1995) and some against it (e.g., Orts & Strudler, 2002; Phillips & Reichart, 2000).

Given this debate, it is important to acknowledge that the natural environment and climate change impacts must be considered in businesses' strategic management processes (Haigh & Griffiths, 2009). Due to the relatively small land and population size of SIDS, there tends to be fewer stakeholders overall, especially in the private sector, meaning that any given stakeholder's actions or reactions can lead to comparatively bigger domestic impacts than in other countries. Thus, for enterprises in a SIDS context, incorporating their stakeholders' climate change impacts and adaptation actions is of strategic interest, since the close interdependencies amongst the stakeholders mean that one stakeholder's decisions can have significant ripple effects around the country.

Using the stakeholder approach, the in-depth interviews explored potential attributes and perceptions of selected stakeholders in the industry on the mechanisms and CCA financing more generally. Many papers examining international tourism have used a comparable number of qualitative, in-depth interviews, demonstrating how a small but targeted sample size can lead to rich findings (Osorio & Best, 2015; Mansfeld & Korman, 2015; Wong et al., 2012).

The interviews were conducted in person (five participants) and via Skype (four participants) during two months in mid-2014, completed in English (common language of the interviewer and all interviewees), based on open-ended and follow-up questions, and lasted 45 minutes on average. All interview partners were offered anonymity, an option accepted by only the tour operator representatives. Table 2 provides an overview of the interviewees. These individuals were selected based on their (i) expertise on the topic and (ii) representing a broad range of stakeholders from the tourism industry, donor organisations, and local governments. Most interviews with government representatives were conducted at an international climate change negotiations event in Bonn. The other interviewees were identified through reviewing existing literature and recommendations from other interviewees (snowball sampling).

Table 2. Overview of interviewees

Abbr	Operating Location	Institution	Position
SL	St. Lucia	Ministry of Sustainable Development, Energy, Science and Technology	Chief Sustainable Development & Environment Officer
PNG	Papua New Guinea	Office of Climate Change and Development, Government of PNG	Manager of Reducing Emissions from Deforestation and Forest Degradation Projects

Abbr	Operating Location	Institution	Position
MA	Mauritius	Ministry of Environment & Sustainable Development	Divisional Environment Officer
SI	Solomon Islands	Ministry of Environment, Climate Change, Disaster Management and Meteorology	Under Secretary / Technical
UN	Mauritius	United Nations Development Programme	Regional Technical Adviser
UNW	South East Asia	United Nations World Tourism Organization, Consulting Unit on Tourism and Biodiversity	Project Manager, Sustainable Development for Tourism
TO1	Caribbean, Africa, Indian Ocean	Tourism Operator 1, multinational tourism corporation within the range of the 5 biggest tour operators in Europe	Head of Sustainability Management
TO2	Caribbean, Africa, Indian Ocean	Tour Operator 2, multinational tourism corporation within the range of the 5 biggest tour operators in Europe	Higher Management
WT	Globally	World Travel and Tourism Council	Policy and Research Director

The semi-structured interviews were recorded, transcribed, coded, and analysed qualitatively (Liamputtong, 2013; Bryman, 2012; Babbie, 2010) to extract details for and interviewees' perceptions regarding each investigated mechanism. The findings were further enriched through a targeted literature search identifying existing examples and attributes of each mechanism. The main limitation of the data is the underrepresented tourism industry stakeholders, such as from accommodation, boating, and diving; however, the interviewees indicated that they work closely with these sectors and revealed insights into their perceptions, helping to overcome this gap.

Mechanisms for Involving the Tourism Industry in Adaptation Finance

The results demonstrated stakeholder perceptions of CCA financing for the tourism industry and provided details of six mechanisms for involving the industry in financing its adaptation, namely: (i) public-private partnerships (PPPs); (ii) building standards and regulations; (iii) adaptation taxes or levies; (iv) adaptation funds; (v) water use management; and (vi) risk transfer mechanisms.

Perceptions of and on Key Stakeholders

Most interviewees estimated the tourism industry's awareness of climate change as being high. Climate change is apparently recognized by the industry as a big 'trend' that will affect business in the future. At annual business summits of the largest global lobby organisation of the industry, climate change "always comes up whether [they] plan to talk about

it or not" (WT). Studies confirmed this perception on climate change of the tourism industry in SIDS (Belle & Bramwell, 2005; Méheux & Parker, 2006).

Awareness does not automatically lead to action. In fact, the overall willingness of the sector to participate in financing CCA was estimated as being low by seven of the nine interviewees, even though it is highly context-dependent. The type of tourism enterprise, their abilities to deal with climate change, and the level of potential benefits of an adaptation measure for their business were key factors shaping the willingness to participate in funding adaptation (TO1, TO2, WT, UNW). The tourism industry representatives also considered governments to be responsible for many adaptation actions (WT, TO2). Another major concern raised by private sector representatives was the transparency of financial flows within local governments (TO1, TO2, WT).

WT, similarly to Pauw & Pegels (2013), raised the question of whether the private sector actually "bothers about" or understands adaptation terminology. They suggested that many enterprises incorporate adaptation measures, and thus fund them, in their daily activities without being aware that they could be termed 'adaptation' or labelling them as such. Other reasons for inactivity (Wright, 2013; Becken & Hay, 2012; Sovacool, 2012; Becken, Hay, & Espiner, 2010; Turton et al., 2010) included: (i) uncertainties about climate change impacts as well as the context of other changes being experienced; (ii) most objects of attraction for tourists being 'common goods' and, therefore, government owned or managed; (iii) the conflicting time horizon of climate projections, regular economic investments, and expectations of return-on-investment; and (iv) the framing of climate change in relation to other more immediate challenges to economic profitability.

The latter could also translate into governmental priority setting. Governments often become more concerned about immediate matters rather than aiming for long-term adaptation strategies, or they need to make policy decisions in a "context of uncertainty and complex socio-economic, cultural, and political relationships" (Belle & Bramwell, 2005; UNW). The government interviewees revealed that they were also cautious about creating extra burdens (or something perceived as such) for the already competitive and price-sensitive tourism industry through taxes and regulations (SL, PNG, MA, SI).

Regardless, adaptation measures would have the highest chance of being implemented when mutual benefits are created, especially in the short-term (UNW, TO1, TO2). The government could aid such a process through reducing uncertainty through legal security, clear public policies, transparency, and incentive frameworks that are influential factors in attracting and sustaining tourism investment (Christiansen et al., 2012; Persson et al., 2009).

Public-Private Partnerships (PPPs)

PPPs can be broadly outlined as arrangements between the public and the private sectors (Hodge & Greve, 2007). There

is not a single, widely accepted definition of PPP, but most definitions include it as being a form of collaboration to pool resources for reaching a common aspiration (UNWTO, 2015; Grimsey & Lewis, 2004; Osborne & Murray, 2000; Gray, 1991).

A key determining factor of PPP initiation is expectation of mutually beneficial outcomes, at least in theory. The main incentives for initiating PPPs can be combining specific qualities, such as know-how, of both public and private sectors to create a better result (Rosenau, 2000) by using the innovative capacity of the private sector and potentially garnering additional funding (Christiansen et al., 2012; Hodge & Greve, 2007). In particular for many SIDS with a limited public budget and small development agencies, this can be an important motivation to realize PPP projects. Thus, "PPPs are important, and often vital, elements in the establishment of tourism-based initiatives and the improvement of the market competitiveness of destinations" (UNWTO, 2015, p. 12).

The UNWTO representative saw a high potential for international donors to initiate PPPs for adaptation in SIDS. However, "the extent to which PPP[s] [are currently] employed in climate adaptation is very limited, and even more so in the tourism sector" (Wong et al., 2012, p. 136). Wong et al. (2012, p. 136) investigated "if and how ... [PPPs] may help the tourism sector in ... [SIDS] in the South Pacific [to] adapt", concluding that the tourism sector stakeholders "were positive about forming PPPs for adaptation" (Wong et al., 2012, p. 140), although one critic did not trust the reliability of the government as a potential partner.

The main barriers to PPPs for the tourism industry were identified as (Wong et al., 2012; WT; Huxham & Vangen, 2002): (i) limited interest in participating financially in projects run by or with stakeholders who can adapt in other ways (TO1, TO2); (ii) setting common aims; (iii) trust; (iv) and differences in work culture. Despite good practice examples, PPPs experienced a range of bad circumstances and were criticized about their effectiveness. This criticism covers: (i) privatizing government assets and services through PPPs which effectively yields ownership to the private sector with limited interest in public goods; (ii) limited transparency; (iii) unsuccessful transfer of risks, and (iv) mainly driven by industry rather than public interests (Roehrich, Lewis, & George, 2014; Sanger & Crawley, 2009; Hodge & Greve, 2007; Hodge, 2004).

Overall, PPPs appear to be a promising mechanism to realize adaptation projects, particularly of large infrastructure interventions. Competing interests, constraints, and stakeholder perceptions need to be factored in when designing measures. Building Standards and Regulations

High quality building standards for SIDS' tourist infrastructure can significantly decrease the negative impacts of climate change (Mahon et al., 2013). Conversely, the quality of water and resource management can suffer in the absence of regulations. In SIDS, much accommodation was built on or near the seafont

in order to fulfil customer desires for beach and water tourism. Thus, tourism developers often took a calculated risk in locating their business on the shoreline, if governmental regulations are absent (Mahon et al., 2013)—and sometimes even when there are governmental regulations against the practice. The tour operator representatives clearly stated that this situation relates to their business practices of cooperating only with resorts close to the shoreline, since tourist demand patterns highlight beachside locations (TO1, TO2).

All countries represented by an interviewee, apart from Mauritius where such laws are currently being drafted, have specific building codes that consider climate change impacts, such as sea-level rise (MA, PNG, SI, SL). From the authors' perspective, there might be a self-selection bias in that representatives from other governments potentially did not make themselves available for interviews due to lack of interest in managing the tourism industry. Yet code enforcement seems to be a major challenge in all the participating countries (SI, SL, MA). Another major issue was that rebuilding tourism infrastructure after disasters often takes place in the same disaster-prone areas (Mahon et al., 2013). Regulatory frameworks to support the industry in dealing with climate change impacts can include monitoring and maintenance regimes within building codes; full planning and design standards and regulations; and professional certification for engineers, architects, and planners. It remained an open question if such regulations would be enforced in an economy that is highly dependent on tourism, even though enforced building standards tend to make a positive impact on adaptation and wider risk reduction (Spence, 2004).

Adaptation Taxes or Levies

Taxation or levy systems could generate additional funds to finance adaptation measures. At the moment, no such specific adaptation taxes or levies for the tourism industry are implemented in any of the islands represented by interviewees. Although many SIDS have departure taxes/tolls or 'green' fees for tourists, none directly addresses or funds adaptation. MA, PNG, and SI indicated that they are very cautious about creating an extra burden (or something perceived as being a burden) on the increasingly competitive tourism enterprises operating in their countries. WT stated, "generally speaking, taxing tourism is not helpful; tourism is enormously price-sensitive". Apart from these concerns towards regulation, two interviewees said that fiscal mechanisms such as taxes or levies would be the most efficient way to raise funds for adaptation (TO1, TO2). Governments could also use funding from taxes independently for adaptation interventions.

This autonomous management of funding was, on the other hand, a big concern raised by the industry (TO1, TO2, WT). They mentioned that taxes in many cases were used to "fix holes in national budgets" and they were afraid that adaptation taxes could be misused or even disappear in other channels. Therefore, a clear trust issue emerged and any taxation system

would need to be transparent and carefully designed so as not to trigger negative consequences, or perceived negative consequences, for the sector. Transparency International's (2016) corruption perceptions index gives wide-ranging results for tourism-dependent SIDS (e.g., Barbados is tied with the USA at #16, but Dominican Republic is ranked at #103), although most SIDS are not listed. Fiji, for instance, is not listed and has a high rate of corruption perceptions (Pathak, Naz, Rahman, Smith, & Nayan Agarwal, 2009).

Adaptation Funds

Adaptation funds are funds that are created to pool finance to incentivize action or invest in adaptation measures, projects, or programmes. Adaptation funds could be set up at any governance level: global, regional, national, or local. Most interviewees rated adaptation funds as being a feasible mechanism (UNW, UN, MA, SL, SI, TO1). All industry representatives preferred adaptation funds as a way to finance adaptation when compared to taxes or levies (TO1, TO2, WT). Regional, national, or local funds were perceived to be better than international ones due to fewer organisational challenges and the possibility of reconciling differing interests.

Regional and local funds could be initiated, sourced, and managed by governments, independent institutions, and/or the private sector (WT). The capital raised was suggested as financing mainly visible adaptation measures, such as building structural defences along the shoreline (ex-post) or rebuilding infrastructure to factor in climate change impacts (ex-ante).

No country was identified as having a tourism industry that implemented a climate adaptation fund as part of its funding structure. However, the Caribbean region implemented the Caribbean Catastrophe Risk Insurance Facility (CCRIF), which could be interpreted as functioning in a comparable manner to an ex-post orientated adaptation fund (CCRIF, 2014). PNG, SI, and MA were all positive about implementing such funds in their region and currently plan to set up a national climate change fund that partly finances adaptation. Nonetheless, they were cautious about involving the tourism industry as a source of funding (MA, SI), as in their view, doing so could potentially discourage the industry from investing. This reaction once more demonstrated the dependency (or assumed dependency) of SIDS on the tourism sector, along with the assumption that requests or demands for adaptation financing will limit investment in tourism, thereby limiting the governments' negotiating power. As potential countermeasures, increasing a fund's transparency and possibly involving the tourism sector as managing board members seemed to raise the industries' acceptance of such a mechanism (TO2, WT).

Water Use Management

Another potential mechanism to fund CCA efforts in the tourism industry is sustainable water management practices for both demand and supply, including the treatment of wastewater

to avoid health impacts and the reduction of overall water use. Sustainable water management practices are always needed, given how excessive water use can be in the tourism industry (Garcia & Servera, 2003); but such measures can only be regarded as adaptive in nature, particularly in destinations where climate change impacts the availability of fresh water or the negative consequences of untreated wastewater. These trends are expected in most SIDS due to saltwater intrusion driven by sea-level rise (IPCC, 2014b; UNWTO et al., 2008). Some SIDS already import fresh water using tanker ships, including Fiji, Tonga, Bahamas, Antigua and Barbuda, and Nauru (United Nations Educational, Scientific and Cultural Organization [UNESCO], 2012). This problem is further reinforced by tourism development trends towards higher fresh water use, leading to the situation wherein “tourism development in many areas of the world may become less sustainable or no longer feasible” (Gössling et al., 2012, p. 13; Charara, Cashman, Bonnell, & Gehr, 2011; Bishop, 2010).

Apart from the constraint of water availability for tourism, poor water quality and media coverage of water issues can create image problems for destinations (Hall, 2010; Hall & Stoffels, 2006), implying a need for tourism to engage more proactively in water management (van der Velde, Green, Vanclooster, & Clothier, 2007; Hall & Härkönen, 2006). A positive aspect of improved water management is the potential to simultaneously reduce costs since “it seems beyond doubt that most of the measures that can reduce water use are economical” (Gössling et al., 2012, p. 13). The UNWTO representative stated that this framing of the environmental problem in economic terms was in his experience the key strategy for convincing the private sector to act in a developing country context.

Risk Transfer Mechanisms

The most common risk sharing and transfer mechanisms in the tourism sector are insurance-related schemes, in which investments could easily be tracked. These mechanisms usually “manage risks that would be too large for companies or individuals to cover on their own” (Warner et al., 2013, p. 11). Particularly in the context of climate change, they could play a key role for tourism firms in managing risk and enabling investments and operations despite uncertainties under climate change.

While insurance can raise awareness about risk management and adaptation, “climate change may bring some residual risks which cannot be transferred to the insurance market cost-effectively” (Warner et al., 2013, p. 13) and might discourage adaptation. UNFCCC (2012) estimated that for countries which are highly exposed to slow-onset climatic processes, such as sea-level rise, traditional risk transfer approaches could be unsuitable. This is the case if two main preconditions for traditional insurance schemes to work are not fully applicable (Warner et al., 2013, p. 14): “the unpredictability of a specific event and ability to spread risk over time and regions, between individuals/entities”.

An alternative investigated and piloted scheme is weather-index based insurance products (Munich Climate Insurance Initiatives [MCII], 2014). In contrast to traditional insurance schemes, the weather-index based payout allows an immediate payout after a disaster, thus payouts are not bound to the value of the asset, but insurance credits can be purchased and payouts are related to the amount of credits which an enterprise holds. Most of the country representatives had already heard about such schemes, in contrast to the industry representatives, although the interviewees stated that majority of the bigger tourism enterprises in SIDS are already insured.

Discussion

Based on the mechanisms identified by the interviewees and literature, this section discusses the influence of interests and operational scales on the feasibility of implementing the mechanisms.

The results imply that the tourism industry is more likely to support some mechanisms than others, mainly emerging from the tour operator representatives stating that they cannot use adaptation projects as effective marketing tools. Considering the possible drivers for the private sector to invest in its own CCA (Pauw & Scholz, 2012), the industry interviewees indicated interest in protecting their business from negative impacts through risk transfer mechanisms and exploiting beneficial opportunities through water management. Corporate social responsibility was rarely mentioned and could not be depicted directly by any single mechanism, whereas water efficiency could possibly be used for marketing purposes.

While the responses indicate that industry representatives have a limited understanding of adaptation and its benefits, this does not translate to invalid views. Rather, an improved understanding could yield a higher and more positive perspective and motivation for the tourism industry to fund its own CCA. Informational programs from SIDS governments might convince the tourism industry to be more involved in financing its CCA—or could at least seed the ideas for the tourism industry to start engaging in dialogue with governments.

The other identified mechanisms appear to have fewer direct positive rewards for the industry, so the interviewees intimated reluctance to incur the additional costs assumed to be required, corroborating earlier findings from Fiji (Becken, 2005). Similarly, Sovacool, Linnér, and Klein (2017) document limited results from an adaptation fund for Maldives and Vanuatu, amongst other countries, raising the question of why the tourism industry should contribute to such a fund. Thus, the mechanisms can be clustered according to the perceived interests of government and of the private sector in initiating the mechanism for increasing adaptation financing (Figure 1). SIDS governments would

need to play a significant role in initiating mechanisms, but then they might give in to tourism industry lobbying against the mechanisms based on perceived costs.

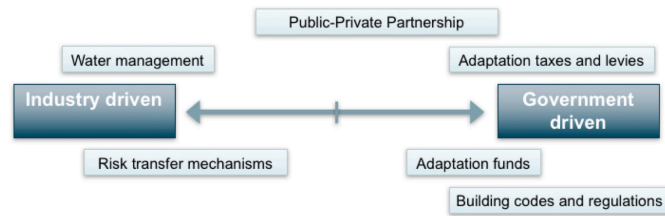


Figure 1. Categorisation of mechanisms on CCA financing according to the likely initiator

In this context, the differing operational scales and abilities of stakeholders for dealing with climate change should be considered for a clearer picture of the feasibility of implementing certain mechanisms. Interest in adaptation engagement tends to be lower where adaptive capacities are higher and vice versa (Hess, Pauw, & Papyrakis, 2015), suggesting that the industry might favour certain mechanisms precisely because these stakeholders feel that their adaptive capacities are low, so they need to act. Industry stakeholders who are bound to a specific location, such as hotels, beach owners, and protected area tour operators, tend to be less flexible for relocating their operations, if it is even possible, thereby increasing exposure to risks and potentially favouring prompt adaptation action.

SIDS governments should therefore consider factoring in industry operational scale and interests when deciding how to act on financing tourism industry adaptation. This conclusion is supported by Pauw, Klein, Vellinga, and Biermann (2016) who detailed specific limitations for monitoring and reporting private sector financing for climate adaptation. In fact, the results demonstrate that, whereas multinational tour operators tend to have the highest flexibility for selecting and adjusting mechanisms, their willingness to finance adaptation appears to be low. Conversely, the tendency is the opposite for more locally bound stakeholders. Nonetheless, businesses looking towards the long-term, or businesses seeking government direction because the industry's adaptability is low, might be supportive of government interventions.

Conclusion and Recommendations

This exploratory study showed that several promising mechanisms exist for involving the tourism industry in financing its own CCA in SIDS as viewed by the interview respondents. The industry representatives perceived that the willingness to become involved may vary significantly due to differences in the industry's knowledge of, ability in, and interest regarding CCA as well as their operational scale. On a destination or regional scale, adaptation funds, risk transfer

mechanisms, and PPPs proved to be particularly promising. Overall, private adaptation financing initiatives were widely acknowledged by the interviewees as being preferable, as they are seen to be more transparent than taxes or levies, while the industry could hold positions on the fund's management board.

Despite the overall potential, in-depth interviews and literature review pointed to a number of challenges in involving the tourism industry in financing its own CCA in SIDS. Varying incentive structures and the price sensitivity of the sector suggest that government frameworks would be needed to effect substantive action. Moreover, this study showed that approaching the sector to support adaptation financing should likely be based on demonstrating cost-effective interventions or possible costly threats. Such an approach typically increases the chances of gaining the attention of firms, raising awareness, and creating a knowledge base on which the necessity of supporting adaptation action could be communicated.

Further research should be undertaken to supplement these exploratory findings for each identified mechanism and for possible interactions amongst them. Building on the findings of the study, follow-up stakeholder group interviews in SIDS could reveal how stakeholder interdependencies and power dynamics could further shape the potential of involving the SIDS tourism industry in adaptation financing. Quantitative surveys alongside qualitative interviews covering more stakeholders could be undertaken to determine the wider tourism industry stakeholders' perceptions of mandatory and voluntary involvement in adaptation financing. The data would contribute to scoping the practicality and feasibility of implementing certain mechanisms in specific SIDS contexts. The opportunity also exists to further test assumptions of stakeholder theory in SIDS contexts, to indicate whether or not the theory would need to be modified to account for the small, closely knit populations. Thus, continuing to examine tourism industry financing of CCA in SIDS can make both theoretical and empirical contributions to the literature.

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Adaptive capacity of indigenous peoples to changing climate: The case of the *Aytas* of Floridablanca, Pampanga, Philippines

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Abstract

The livelihoods of *Aytas* of Floridablanca, Pampanga, Philippines are dependent on natural resources, which are prone to climate change impacts. To assess their adaptive capacity, this paper analyzed the different resources available in their community using the Sustainable Livelihoods Approach Framework. The five livelihood assets (human, natural, financial, social, and physical) of the *Aytas* were accounted for and used as indicators for the Household Adaptive Capacity Index (HACI).

The resulting HACI was 0.49, indicating a medium-level adaptive capacity, limited by poor infrastructure, high dependence on agriculture for income, high poverty incidence of 72 percent, low level of education, and social capital bounded mostly in interactions. Also, farming income of the *Aytas* was highly seasonal and vulnerable to typhoons, prolonged drought, and excessive rains.

Having limited livelihood assets, *Aytas* will find it difficult to adapt to climate change-related impacts. As such, they need support to enhance their adaptive capacity. This paper recommended that programs and projects, which enhance their adaptive capacity, be formulated in consideration of the existing indigenous knowledge, values, and belief systems, as well as their assets.

Keywords: Climate change · indigenous people · adaptive capacity · sustainable livelihood

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Introduction

Indigenous peoples (IPs) are generally dependent on natural resources for their livelihood. However, there have been constraints on the use of these resources to achieve sustainable development in their ancestral domain (Sobrevilla, 2008). To address this, the United Nations Development Program (UNDP, 2010) has provided interventions to assist IPs and concerned government agencies in the areas of leadership, governance, empowerment, and community development. Additionally, emerging as an area of concern is the adaptive capacity of IPs to climate change. The IPs often inhabit marginal areas in fragile ecosystems that are vulnerable to climate change (Salick & Byg, 2007; Baird, 2008), which threatens the IPs' ancestral domain as well as the security and sustainability of their livelihoods.

Vulnerability is composed of exposure (e.g., exposure to climate change related events), sensitivity (e.g., poverty or resource-dependent livelihoods), and adaptive capacity (Turner et al., 2003). An entity is vulnerable when it is prone to and incapable of dealing with the negative impacts of climate change (Intergovernmental Panel on Climate Change [IPCC], 2007). Exposure is the presence of people, livelihood, environmental services and resources, or other assets in places that could be adversely affected (IPCC, 2014). Meanwhile, sensitivity refers to the tangible characteristics of human beings, infrastructure, and environment to be affected by a hazardous phenomenon due to susceptibility (Cardona et al., 2012). Poverty and reliance on natural resources for livelihood, for instance, can make IPs more sensitive to the impacts of climate change (Baird, 2008; Cardona et al., 2012).

Adaptive capacity, especially when improved, could reduce vulnerability. It enables "systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences" (IPCC, 2014, p. 1758). As a household or community obtains the capacity to adapt, its vulnerability decreases even if it may be extremely at risk to climate change (Zhu et al., 2011; Cardona et al., 2012).

Vulnerability encompasses larger socio-economic processes that may marginalize people and make them more susceptible to impacts of disasters. Certain communities or sectors of society may have persistent and intractable sensitivities; measures that fail to address them may undermine their success and sustainability (Nelson et al., 2007 as cited in Miller et al., 2010). In order to lessen the probability of creating unsustainable strategies or undermine adaptive capacity, the political, cultural, and socioeconomic factors should be addressed, and available assets and indigenous knowledge accounted for (Nawrotzki & Kadatska, 2010; Ingram et al., 1981 as cited in IPCC, 2001).

This study examined the different livelihood assets of IPs to identify areas of intervention that could improve their adaptive capacity to climate change. It focused on the *Ayta*¹ Indigenous Cultural Community (ICC) in Floridablanca, Pampanga, Philippines. Results of the study could provide lessons to other IP communities.

Methodology

Analytical Framework

The adaptive capacity of the *Aytas* of Floridablanca to climate change was assessed using the Sustainable Livelihood Approach (SLA) Framework (Figure 1) as it allows a deep understanding of the livelihoods of poor people (International Fund for Agricultural Development [IFAD], n.d.). Specifically, data on the five types of assets, or capital, (Department for International Development [DFID], 1999) that affect livelihood were collected. The study collected data through survey, focus group discussions, key informant interviews, and secondary sources.

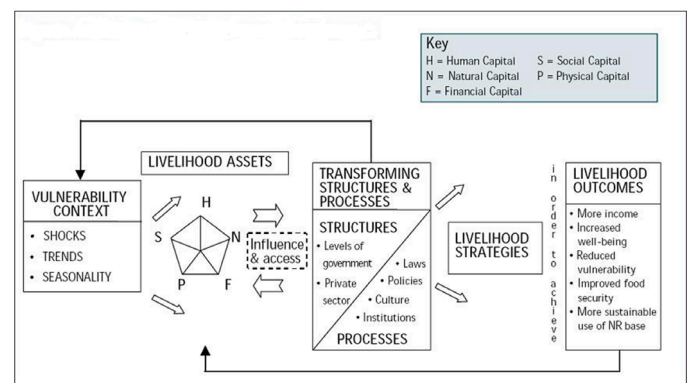


Figure 1. Sustainable Livelihood Framework (DFID, 1999)

Livelihood assets refer to various kinds of capital which are used to produce livelihood either directly or indirectly. In effect, a number of products can be created through it. These products can be used to replace depleting resources or as investment for impending livelihood opportunities. The SLA analyzes how the five types of assets affect people's livelihoods, as well as the relationships between and among them. The DFID (1999) categorized the assets as follows (as cited in Haidar, 2009, p. 6):

Natural capital – consists of land, water, and biological resources such as agriculture and forestry.

Physical capital – refers to the kind of asset which is created by economic production such as infrastructure like roads, transport, irrigation works, energy, communication, schools, and shelter.

¹ *Ayta* (or *Aeta*) is an indigenous group in Central Luzon, Philippines. The Ancestral Domain Sustainable Development and Protection Plan of *Ayta* Tribe of Floridablanca refers to them as mountain people described as having dark skin, short and small frame, kinky hair, snub-nose, and big black eyes.

Economic/Financial capital – consists of stocks of money or other savings in liquid form, easily disposable assets such as livestock, and other resources such as savings, credit, and income from employment, trade, and remittances. It also includes household members' occupation, household ownership of assets, distribution within society of financial savings, access to credit, and debt levels.

Human capital – is determined by household size, education, age, and health of household members.

Social capital – are assets derived from membership in a group such as rights or claims including groups and networks, collective action and cooperation, social cohesion and inclusion, empowerment, and political action.

Data on the five different assets were used to analyze relationships between assets at the household, community, and regional levels with a focus on better understanding the vulnerability to climate variability and change for the *Aytas* of Floridablanca.

² Source: NCIP Region III Pampanga Service Center, Floridablanca, Pampanga

Study Site

The study covered the *Aytas* in the Floridablanca ICC (Figure 2). Floridablanca is a first-class municipality located in the western part of the Province of Pampanga. It has a Type I climate marked by: (a) dry season from December to April and (b) wet season for the rest of the year. There are four cultural minority settlements in Floridablanca: Barangay Nabuclod, Barangay Mawacat, Sitio Malabni, and Sitio Camatchile. These settlements are rural areas and approximately 30 minutes away from the *Poblacion*, the center of the municipality. The *Aytas* represent 4.64 percent of Floridablanca's 2010 population of 110,747 (PSA, 2014). They also comprise 27 percent of the total *Ayta* population of 19,010² in the province of Pampanga.

Data Collection and Analysis

In coordination with the National Commission of Indigenous Peoples (NCIP) in Region III, the study sought the approval of the Floridablanca *Ayta* ICC to collect data. Upon the release of the Certification Precondition, a certificate of the *Aytas*' approval of the study, data collection ensued. Coordination with the local government unit of Floridablanca was also done.

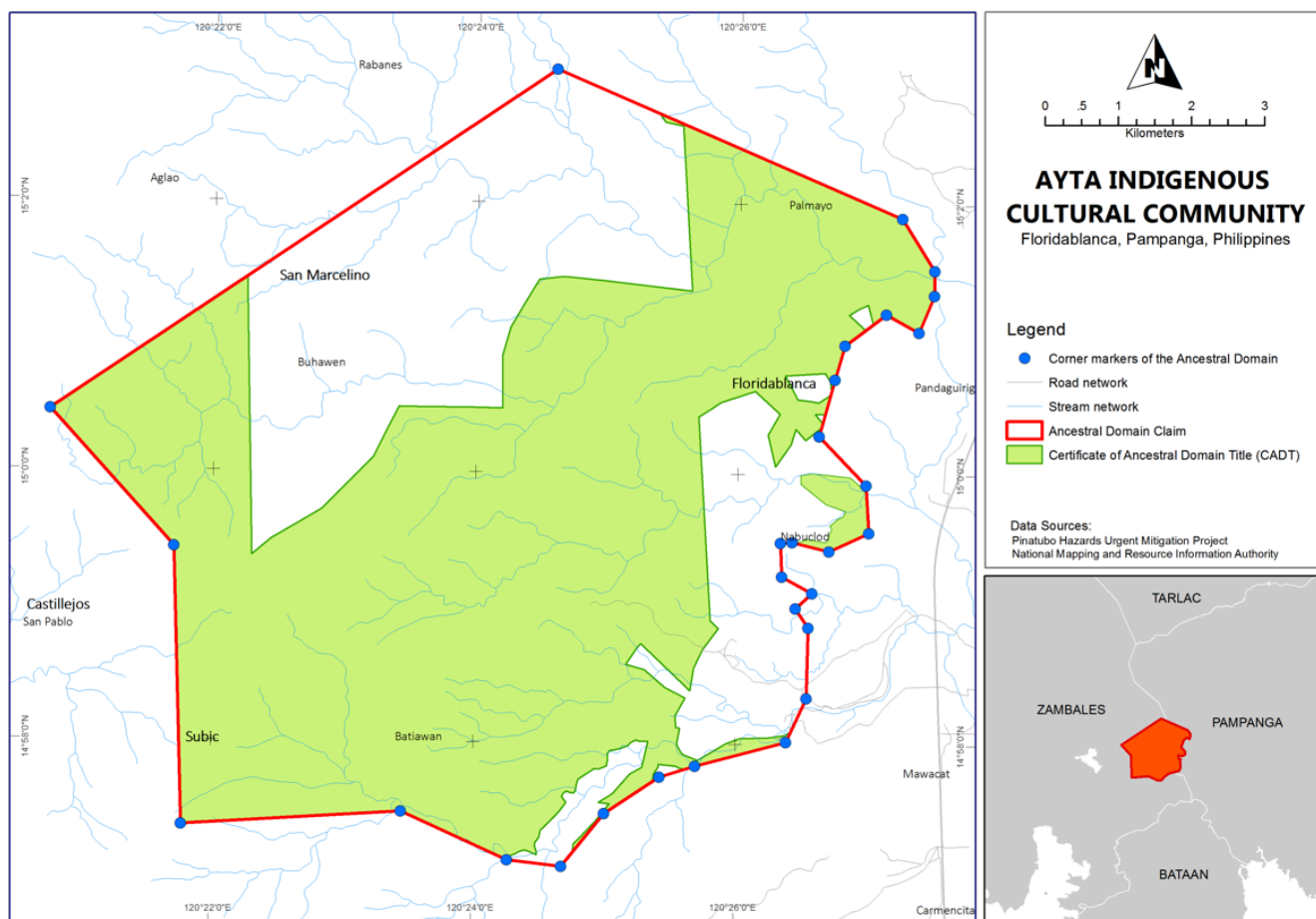


Figure 2. Boundary Map of Ancestral Domain of Floridablanca Indigenous Cultural Community based on the Certificate of Ancestral Domain Title and the Ancestral Domain Claim of the Floridablanca ICC, 2016

Data on livelihood assets, as well as observed climatic changes and their impacts on livelihoods and resources, were collected from primary and secondary sources. Primary sources include the *Ayta* households who participated in the survey. A total of 60 out of 816 households from Sitio Camachile, Barangay Nabuclod, and Barangay Mawacat were purposively sampled based on their accessibility. The distribution of the households per location in the ICC is indicated in Table 1.

Table 1. Distribution of respondents per location in Floridablanca ICC, 2014

Location	Number of Respondents	Percent
Sitio Camachile	28	46.67
Barangay Nabuclod Proper	19	31.67
Barangay Mawacat	13	21.67
TOTAL	60	100.00

Nine key informants from NCIP Region III, Local Government Units, Municipal Agriculturist Office, Municipal Social Welfare and Development, and the Provincial Environment and Natural Resources Office were also interviewed to identify policies, programs, and projects affecting the *Ayitas*' access to resources. Their respective offices provided documents which were reviewed for secondary data (e.g., climate, infrastructure, markets, and natural resource stocks).

The specific data collected for the livelihood assets were the following:

Natural capital – average agricultural land area, land ownership, source of irrigation, and proportion of respondents who rely on the forest for livelihood;

Physical capital – distance from Poblacion, mode of transportation, type of road, type of house material, number of storeys, location of house (e.g., along the slopes, coastal, plain), average estimated value of house, main source of power, source of drinking water, distance of drinking water source, existence of early warning system, type of evacuation center, distance of house from designated evacuation center, accessibility of evacuation center, source of information, and frequency of receiving information;

Economic/Financial capital – average annual income, sources of income, annual income level, savings, loan acquisition, and source/s of loan;

Human capital – education, attendance to training, and types of training attended; and

Social capital – existence of conflict/issues, existence of organizations/institutions, membership in organizations, frequency of interaction, benefits of interacting, sources of assistance, and types of assistance.

These data were used to calculate a normalized adaptive capacity indicator value for each livelihood asset. The method applied is similar to the method used by Peñalba and Elazegui (2011). Normalization was done using the method applied to the Human Development Index by the UNDP (Anand & Sen, 1994) as shown in the following equations:

(1) Normalized value _(where higher is better) is equal to:

$$\frac{\text{Value of the indicator to be normalized} - \text{Minimum value of all indicators}}{\text{Maximum value of all indicators} - \text{Minimum value of all indicators}}$$

(2) Normalized value _(where lower is better) is equal to:

$$1 - \frac{\text{Value of the indicator to be normalized} - \text{Minimum value of all indicators}}{\text{Maximum value of all indicators} - \text{Minimum value of all indicators}}$$

Meanwhile, the average of the normalized indicator values represented the overall Household Adaptive Capacity Index (HACI). Values for the indicators and index were between 0 and 1, with 1 signifying the highest value and 0 signifying the lowest value (Peñalba & Elazegui, 2011).

Results

Profile of the Respondents

Most of the respondents identified themselves as household heads (76.67%) (Table 2). They were dominantly male (73.33%) and only two households were headed by a female, typically by widows (3.33%). The average age of the respondents was 43 years old, while the average age of a household (including age of children and relatives living within the same house) was 23 years old. The average household size was 5.5.

Table 2. Characteristics of respondents

Item	Number	Percent
Head of household	46	76.67
Male	(44)	(73.33)
Female	(2)	(3.33)
Spouse of HH head	14	23.33
Male	(0)	(0)
Female	(14)	(23.33)
TOTAL	60	100.00

Sources of income of the households were on-farm cropping (98.33%), off-farm labor³ (15%), non-farm work⁴ (65%), and selling of forest products (40%) (Table 3). Identified alternative sources of income were backyard livestock-raising and domestic remittances from children and relatives.

³ Off-farm labor involves farm work (e.g., transplanting, weeding) done on somebody else's farm.

⁴ Non-farm work includes employment and business which may be agri-based but does not include farm work, e.g., trading, clerical work, retail store operations.

Table 3. Number of households engaged in work by work type*

Item	Number (n=60)	Percent
On (own) farm	59	98.33
Off-farm	9	15.00
Forest-based (charcoal, bamboo)	24	40.00
Non-farm (e.g., employment, business)	39	65.00

*multiple response

Livelihood Assets

Natural Capital

The *Aytas* considered agricultural lands, forest, and water resources within their ancestral domain as their natural capital. Almost all respondents (96.67%) own the land where they live and cultivate, while others either had no land to till (1.67%) or cultivated a relative's land rent-free (1.67%). Based on the *Aytas*' estimation, they own or inherit an average of 2.75 hectares of agricultural land. However, they cultivate only a portion of their farm land per season then transfer to another portion for the next season. This cultural management practice allows the land to lie fallow.

The ancestral domain is also endowed with rivers and springs fit for drinking and other uses at the time of the study. Yet, the respondents did not have proper technology to utilize these for irrigation. Over 93 percent of the respondents depended on rain for irrigation. Others relied on shallow tube wells (3.33%).

The forest is a source of alternative livelihood for 40 percent of *Aytas*. They collect branches from the forest for charcoal making. They also cut bamboo and sell them as house building material.

Physical Capital

Road network. The *Ayta* settlements were located 13 to 16 kilometers away from the Poblacion. The road network to Barangay Nabuclod was cemented but the rest were rough roads accessible only to limited types of vehicles (e.g., jeepneys, four-wheel drives, and tricycles). The bridge linking the main road to Sitio Camatchile was in bad condition and impassable to all types of vehicles. Moreover, the road to Barangay Mawacat was rough and unpaved.

Housing. Most respondents owned houses made of light materials (58.33%), while some owned houses made of semi-permanent materials (mix of light and permanent materials) (25%). The houses were usually one-storey high and built along the slopes (60%) or on flat areas on the mountain (28.33%). Few lived along riverbanks (10%) and one household lived in the lowland area of the ancestral domain. The respondents' average estimated value of their houses was PhP 29,345.

Utilities. Over 88 percent of the households had access to electricity. Meanwhile, 81.67 percent sourced their drinking

water from hand pumps which were communally used; with distances of approximately 500 meters to more than a kilometer away from their homes.

Early warning systems. Forty percent of the respondents were familiar with early warning systems. However, these were limited only to monitoring the river level, warnings/alerts, and pre-emptive evacuations. They also remembered that members of the barangay council roam around the community to alert them of an upcoming calamity.

Other infrastructures and sources of information. The distance of the barangay hall and identified evacuation centers (e.g., school and church buildings) from the households was more than two kilometers. Respondents said that climate-related information was available to the households through news programs on television (91.67%) and radio (50%).

Financial Capital

Respondents had diversified income sources, with an average annual income of PhP 127,659. Still, almost 72 percent of the sample households were poor, earning an amount below the poverty threshold level (Table 4). More than half did not have savings (53.33%). A high loan acquisition rate from formal (18.34%) and informal sources (43.34%) exists.

Table 4. Frequency distribution of households below and above poverty threshold level^a, with savings and with loan

Item	Average (in PhP ^b)	n	%
Total no. of respondents		60	
Annual income	127,659.46		
Below PhP 105,336	46,879.14	43	71.67
PhP 105,336 – PhP 150,000	120,140.00	4	6.67
Above PhP 150,000	397,169.62	13	21.67
Households with savings		28	46.67
Households with loan from formal sources		11	18.34
Households with loan from informal sources		26	43.34

^a 2014 Poverty threshold level is at PhP 105,336 or US\$ 2,237.74 for a family of five projected based on the poverty threshold from years 2000 to 2012 (Philippine Statistics Authority [PSA], 2015)

^b PhP 44.688 = US \$ 1.00 (2014 Average); Source: Bangko Sentral ng Pilipinas, 2016

Human Capital

A big proportion of male (45%) and female respondents (50%) finished only some years in elementary level. Twenty percent of the male respondents were not able to study at all. Meanwhile, a pattern of female respondents receiving more education was observed. Specifically, more female respondents completed high school (12.5%), an alternative learning system education (6.25%), and some years in college (6.25%) (Figure 3).

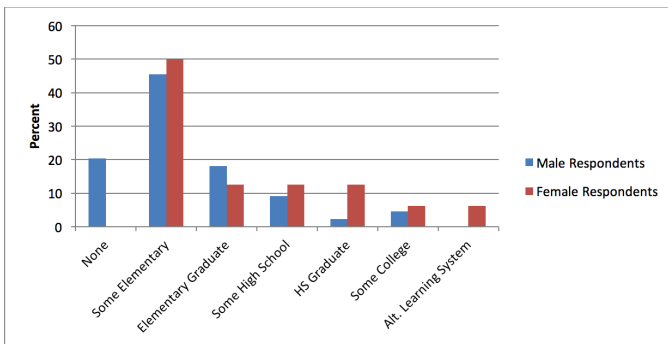


Figure 3. Proportion of respondents who attained a certain level of education

Thirty percent of the *Aytas* were able to attend various trainings or seminars. However, attendance was observed only among *Aytas* involved in the local government (barangay level to municipal level). Everyone who attended a training or seminar said the knowledge gained on climate change awareness, disaster risk reduction and management, and environmental protection was useful.

Social Capital

Existing organizations in the ICC include the Council of Elders and barangay council—the primary decision-making bodies in the community. The former is concerned with community issues (e.g., conflict and encroachment of lowlanders), while the latter on local governance. These councils address issues related to land use (68.7%), water resources (15%), and forest (23.3%).

At the municipal council, the *Aytas* were represented by the Indigenous People Mandatory Representative (IPMR) to ensure their participation in local government planning. Government agencies also provided various assistances. Sixty percent of the respondents had access to some kind of assistance, including financial (41.67%), medical (33.33%), and transportation assistance (8.33%). Other forms of assistance were relief goods and livelihood opportunities (e.g., participation in the National Greening Program).

About 28 percent claimed they were members of local organizations (e.g., Ancestral Domain Federation and religious organizations). More than half (51.67%) of the respondents reported that there was interaction among the *Aytas* which allowed the sharing of information.

The Household Adaptive Capacity Index

The overall HACI was computed by averaging the value of the indicators previously discussed. HACI for the Floridablanca ICC was 0.49, indicating a medium adaptive capacity to climate change (Figure 4).

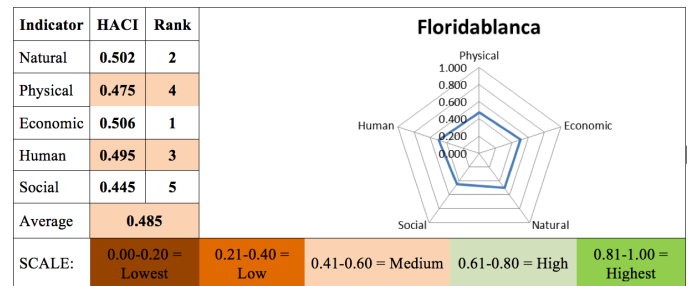


Figure 4. Household Adaptive Capacity Index for the Floridablanca ICC

Impacts of Climate-Related Events

Typhoons, prolonged drought, and excessive rain were identified by the *Aytas* to be the most damaging climate-related events impacting their livelihood and community. However, typhoons were identified by 43 percent of the households to cause the most damage to crops. *Aytas* also observed the occurrence of the following: landslides, damage to houses and roads, decrease in soil fertility, and decrease in quality of drinking water due to muddy springs.

Annual average farm income loss per household (on-farm, off-farm and forest-based income) from the three climate-related events were estimated at PhP 18,206 for typhoons; PhP 11,991 for prolonged drought; and PhP 8,000 for excessive rains (Table 5). Average reported losses in non-farm income due to typhoon were PhP 6,636, while losses due to excessive rain were PhP 2,000. The maximum reported damage caused by typhoons was PhP 100,000, in contrast to PhP 40,000 maximum reported damage caused by prolonged drought and PhP 21,000 maximum damage caused by excessive rains. Farm income losses caused by typhoons varied widely. The overall losses from non-farm income were less variable.

Table 5. Estimated annual income loss of households due to climate-related events

Descriptors	Type of Event		
	Typhoon	Prolonged Drought	Excessive Rain
Estimated Loss in Farm Income (in Peso)			
N	59	11	4
Mean	18,206	11,991	8,000
Minimum	300	1,500	1,000
Maximum	100,000	40,000	21,000
Estimated Loss in Non-Farm Income (in Peso)			
N	25 ^a	-	1 ^a
Mean	6,636	-	2,000
Minimum	400	-	2,000
Maximum	30,000	-	2,000

^a Out of 39 respondents with non-farm income

Occurrence of climate-related events caused sickness to a few households (Table 6). Having been exposed to weather elements under almost the same living conditions over time, these households observed that the changing pattern of extreme climate events in recent years affected the health of some family members. Typhoons induced the most number of sickness (e.g., fever, cough, cold, and diarrhea), affecting 25 percent of households. During prolonged drought, the households experienced cough, colds, nose bleeding and elevated blood pressure; while during excessive rains, they experienced cough and colds.

Discussion

Ayta households are generally young—the household heads were of middle age and their children were young—indicating a high dependency ratio. Their household size (5.5) was bigger than the national average of 4.6 (PSA, 2012a). They had diversified income sources dependent on natural resources. Some engaged in various types of non-farm work that were less vulnerable to extreme climate-related events. Some families received domestic remittances from children who worked outside Pampanga.

The *Aytas'* ancestral domain served as their natural capital. Almost every household claimed ownership to an average of 2.75 hectares of land. Their indigenous practice of land fallowing caused them to cultivate only approximately one-third of their land per season then transfer to another portion for the next season.

Meanwhile, high dependence on rainfall for planting season resulted from the lack of irrigation system in the study area. Dependence on rain sometimes resulted in delayed planting season and crop damage since respondents found it difficult to transport water for their crops every day.

Available physical capital, in terms of functioning infrastructures, was limited. Most road networks were not paved while the bridge going to Sitio Camatchile needed rehabilitation. Housing materials used by *Aytas* were not

strong, could easily catch fire, or could easily be destroyed by strong winds. Access to clean water was a problem during rainy season as water from springs and wells become undrinkable.

Majority of the *Aytas* have electricity in their homes and could receive weather updates from news on radio or television. There were evacuation centers in the community, nevertheless, the approximate distance of 500 meters to two kilometers from their homes make them poorly accessible. In case of a strong typhoon, the residents have to evacuate early. The role of the barangay council in providing early warning and conducting pre-emptive evacuations is important.

Poverty seemed concentrated in the IP Community as 72 percent of the sample households were in poverty in contrast to Floridablanca poverty incidence of only 6.8 percent (PSA, 2012b). Their poverty resulted in their inability to save and tendency to acquire loans from formal and informal sources for farm capital and household needs. Sakadores, or traders, usually provide loans in the form of agricultural inputs in exchange for the *Aytas'* produce. However, Sakadores often buy at prices lower than the prevailing market price.

Human capital level in the community was low as young men stopped attending school as soon as they were physically capable to work, while women stopped at a young age, usually at puberty, since arranged marriage was still practiced. Scholarships were made available to encourage *Aytas* to continue studying, but elders observed that the distance of secondary and tertiary schools in Poblacion from the community and the treatment *Ayta* students experienced (e.g., comparison between aptitude of *Aytas* and lowlanders and discrimination due to ethnicity) affected their enthusiasm for education. Meanwhile, attendance to trainings and seminars was observed only for *Aytas* involved in the local government.

Part of the social capital in the community was the Council of Elders. Even though a barangay council existed in the community, barangay captains still sought permission or advice from the Council of Elders, specifically on issues or conflicts related to the ancestral domain and their customary laws (e.g., encroachment). Other types of conflicts were handled by the barangay council. Social capital formation in the community occurred due to

Table 6. Number of households who reported sickness of family members due to climate-related events

Number of Family Members Affected	Climate-related events					
	Typhoon		Prolonged Drought		Excessive Rain	
	Number	Percent	Number	Percent	Number	Percent
1.00	7	11.67	1	1.67	1	1.67
2.00	2	3.33	2	3.33	-	-
3.00	2	3.33	-	-	-	-
>3.00	4	6.67	-	-	2	3.33
No answer	45	75.00	57	95.00	57	95.00
Total	60	100.00	60	100.00	60	100.00

interaction among families and community members within the *Ayta* community. Through interaction, respondents shared climate-related information including observed changes in weather and disaster warning.

Other existing social networks in the community included the IPMR who represented the community in the local government unit, organizations in which some *Aytas* were members, and government agencies that provided various forms of assistance (e.g., relief goods during disasters).

Utilizing the aforementioned capitals, HACI resulted in a medium adaptive capacity level of *Ayta* households. Households with diversified income sources, especially income from non-farm sources, could be expected to have lower vulnerability because their income sources were less affected by climate-related events. However, 48 percent of the households relied only on on-farm and off-farm income, and selling of forest products, resulting in higher vulnerability since their income sources were easily affected by climate-related events. Adaptive capacity could be limited not only by reliance on on- and off-farm income but also by education gained, training received, household size, and age of family members. In some households, parents might be the only people capable of preparing for typhoons or finding work to recover monetary losses. Limited interactions among community members and the low incidence of involvement in organizations reduced social capital.

Conclusion and Recommendations

The *Aytas* of Floridablanca were vulnerable to climate change because they were dependent on natural resources which are prone to climate change impacts. Despite diversification of income sources, they were still generally poor and had limited assets. These limitations made adaptive capacity in the face of more than one climate change-related impact difficult. The medium adaptive capacity index value reflects this. Since the Luzon regions encounter an average of five destructive typhoons per year, and increase in temperatures and rainfall in the future are expected (Ortega, 2015; Philippine Atmospheric Geophysical and Astronomical Services Administration [PAGASA], 2011), improving adaptive capacity to successive events will be even more challenging.

The *Aytas* need support that complements their assets to improve their adaptive capacity. In order to do so, the five assets must simultaneously be increased. Strategies that protect or enhance their natural capital should be in place, since it is their most valuable asset. Improving infrastructures and utilities available in the area, such as rehabilitation of roads and bridges, projects to utilize water for farm and domestic use, and improving early warning systems would be beneficial in enhancing their physical capital. Additional livelihood opportunities could help reduce poverty and dependence on Sakadores, and would be expected to enhance economic capital. Increasing level of

education through programs addressing discrimination, access to secondary schools, and provision of alternative learning programs would help improve human capital. Social capital in the community had the lowest value among indicators, and enhancing it would enable economic transactions, access to information, collective actions, and flow of assistance through social networks and institutions (Adger, 2003; Zhu et al., 2011). Activities that would initiate collective action (e.g., National Greening Program), increase interaction, and form organizations could be beneficial. Finally, it is essential to offer long-term solutions that will enable participation in increasing adaptive capacity and respect in their indigenous knowledge and customary laws. Programs and projects for the enhancement of adaptive capacity should be formulated in consideration of the existing indigenous knowledge, values, belief system, and natural resources. Such steps are expected to decrease failure of implementation and may lead to improved appreciation by the community.

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Adaptation and adaptive capacity to flooding of farming households: Insights from Mabitac, Laguna, Philippines

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Abstract

Vulnerability to flooding due to climate change results in limited access to resources, soil erosion and/or deposition, and reduced quality of water supply among others, affecting many farming communities. Recognizing the need to assess and better understand the adaptive capacity of farming communities, this study determined the effects of flooding and assessed the adaptive capacity levels of farming households in Mabitac, Laguna, Philippines as a case. Using analytic hierarchy process, it also explored the contribution of human, physical, and financial resources, information, and livelihood diversity in enhancing adaptive capacity. Human resource and livelihood diversity received the highest (0.3087) and lowest (0.0566) weight due to labor-intensive and mono-cropping practices, respectively. About two-thirds (69%) of the farmers have moderate level (0.36-0.50) of adaptive capacity. Their level of adaptive capacity is not associated with their adaptation practices because the decision can be attributed to other factors. Although adaptive capacity is an established factor of household vulnerability, the study showed that it is not a sole determinant of adaptation practices. To increase adaptive capacity and reduce vulnerability to flooding of farming households, the study recommends local policies and programs that are focused on improving livelihood diversity and physical resources.

Keywords: Climate change · adaptation · adaptive capacity · Mabitac · flooding

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Introduction

According to a study by the United Nations University's Institute for Environment and Human Security (UNU-EHS) and the German Alliance Development Works (2011), the Philippines is the third most vulnerable country to climate change. Its geographical location and physical characteristics leave it exposed to an average of 19 tropical cyclones every year (Philippine Atmospheric Geophysical and Astronomical Services Administration [PAGASA], 2013) as well as other climate-related hazards such as flooding, rain-induced landslides, and droughts. Agriculture has been largely affected by the impacts of climate change due to the following: climate variability, seasonality, changes in mean precipitation, and water availability (Wreford, Moran, & Adger, 2010). The role of agriculture as a source of income and food security is highly affected. Climate Change Commission (CCC) (2011) reported that the annual damage to agriculture has reached 3% (PhP 12 B) of the total agricultural production. The said damages led to food insecurity and loss of livelihood especially for the small farming households.

Adaptation and Adaptive Capacity

Adaptation refers to adjustments in ecological, social, or economic systems in response to actual or expected climatic stimuli and their effects or impacts. It also refers to changes in processes, practices, and structures to moderate potential damages or to benefit from opportunities associated with climate change (United Nations Framework Convention on Climate Change [UNFCCC], 2014).

Agricultural adaptation strategies were created since farmers had to save their source of livelihood through switching crops, cultivars, and/or timing of field operations. Another adaptation strategy is to alter crop mix, favoring the relatively higher yield and profitable crop varieties. Agricultural adaptation to climate change can happen in various forms including changes in agricultural land areas, use of irrigation, and technical innovations (Kaiser & Drennen, 1993).

Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (2007) stated that adaptation practices are rooted in adaptive capacities. Adaptation strategies will not be successful unless there is willingness to adapt among those affected. In turn, adaptive capacity can be undermined by a refusal to accept the risks associated with climate change, or by a refusal of key actors to accept responsibility for adaptation (Brooks & Adger, n.d.).

IPCC (2001) defined adaptive capacity as the ability of a certain system, region, or community to adapt to the impacts of climate change. Different determinants of adaptive capacity are known to involve farming households and are used in identifying and assessing the adaptive capacity of a community (McCarthy, Canziani, Leary, Dokken, & White, 2001).

Adaptive capacity works better with the influence of some indicators: having managerial ability; access to information, financial and technical resources, and infrastructure; implementation of policies; and creation of networks. Additionally, adaptation practices are indicators of adaptive capacity in the case of integrating the

traditional practices of farming households (Bhadra, 2012). Farming household's adaptation practices usually include crop diversification, irrigation, water management, disaster risk management, and insurance (Adger, Agrawala, & Mirza, 2005).

Lasco, Habito, Delfino, Pulhin, and Concepcion (2011) reported that farmers in Southeast Asia have been exploring new farming adaptation practices to address climate change such as changing of crop calendars, water management and conservation, pest management, agroforestry, and community-based adaptation, particularly in the Philippines. Government policies and efforts include improving the agricultural extension and services through better access to information, education, and communication (IEC) programs by encouraging local government units (LGUs) to participate in farming trainings and seminars related to adaptation practices (National Economic and Development Authority [NEDA], 2011).

Flooding in Mabitac, Laguna

Mabitac is a fifth class agricultural municipality in the province of Laguna, Philippines. Its location along the coast of Laguna Lake and its topography contribute to its vulnerability to the impacts of climate change, such as flooding. Although not all barangays¹ experience the extreme effects of flooding, majority of them recognize the difficulties in recovering from such. Agriculture is the most common livelihood and source of income of the residents. Farming households are one of the major sectors affected by climate change (Department of Interior and Local Government [DILG], 2013), particularly in times of flooding. Their income, food, and other basic necessities are hinged on the crop growth. The harms of flooding can limit their capabilities to thrive and survive (Pati, Franco, Alcantara, Pacardo, & Resurreccion, 2014). Maintaining high quality and status of agriculture in Laguna is significant in addressing the food instability issue within the province. As an agricultural municipality, it is important to study the relationship of adaptive capacity and adaptation of the farming households.

This study assessed the adaptive capacity to flooding and adaptation practices of farming households in Mabitac, Laguna. Specifically, it (i) identified the effects of flooding as an impact of climate change to farming households, (ii) analyzed the levels of adaptive capacity of farming households, (iii) identified adaptation practices done by farming households, and (iv) determined the relationship between adaptive capacity and adaptation.

Methodology

Site Selection

Mabitac Municipality is vulnerable to climate-related stress such as flooding, and local communities are dependent on farming as the main source of livelihood and income (Mabitac MDRRMO, 2014).

¹ A barangay is a Filipino term referring to the smallest administrative division or a village in the Philippines.

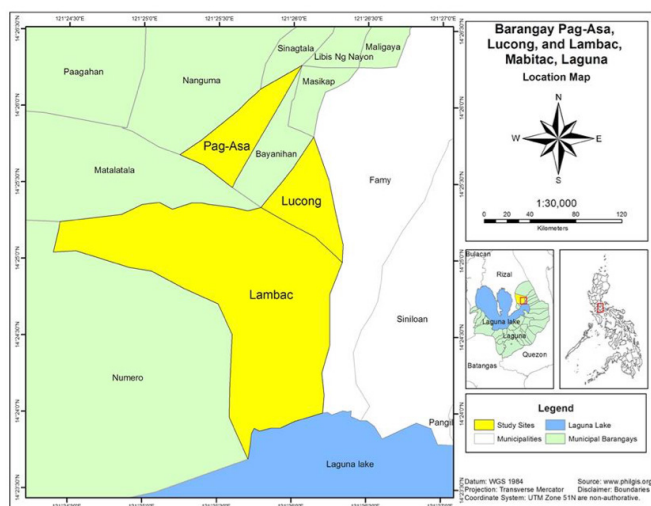


Figure 1. Location map of the three barangays (Pag-Asa, Lucong, and Lambac)

The study focused on the three barangays (Figure 1), namely, Pag-asa, Lucong, and Lambac representing the municipality based on their topography and main source of livelihood.

Data Collection and Analysis

Household surveys, key informant interviews (KIIs), and focus group discussions (FGDs) were employed to generate primary data. A total of 75 farming households in the three barangays, selected through stratified random sampling, were interviewed. Household survey was used to determine the level of adaptive capacity using Sustainable Livelihood Framework (modified and adopted from Defiesta & Rapera, 2014). The assumption is that the adaptive capacity can be measured using the indicators of adaptive capacity of farming households (Table 1). This was supplemented by KIIs with agricultural experts, municipal employees and staff, and resource persons using Analytic Hierarchy Process (AHP) to determine the relative weights of the indicators of adaptive capacity. FGDs were conducted with the leaders of farmers' organizations to elaborate adaptation practices to flooding.

Table 1. Indicators of adaptive capacity of farming households

Indicators	Sub-Indicators	Description	Assumption	Reference
Human Resources	Farming experience	↑ Number of years the respondent has been farming	↑ Adaptive Capacity	Defiesta and Rapera (2014)
	Educational attainment	↑ Number of years the respondent has been farming	↑ Adaptive Capacity	Leary, Conde, Kulkarni, Nyong, and Pulhin (2008)
	Percentage of adults in the household	↑ Number of adults in the household expressed as percentage of the total number of household members	↑ Adaptive Capacity	Defiesta and Rapera (2014)
	Percentage of adults with primary education	↑ Number of adults in the household that finished elementary education expressed as percentage of the total number of adults in the household	↑ Adaptive Capacity	Weir (1999)
	Percentage of adults who are working in the farm	↑ Number of adults in the household who are working in the farm	↑ Adaptive Capacity	Defiesta and Rapera (2014)
	Diseases present in the household	↑ Number of types and frequency of diseases in the household	↓ Adaptive Capacity	Steeg, Herrero, and Notenbaert (2013)
	Percentage of household members having a prevailing disease	↑ Number of household members expressed as percentage having a prevailing disease	↓ Adaptive Capacity	
	Type of training on farming	↑ Number of types of training that the farmers attended in the last five years (2009 to 2013)	↑ Adaptive Capacity	Mungo (2015)
Physical Resources	Farm size	↑ Farm size in hectares	↑ Adaptive Capacity	Defiesta and Rapera (2014)

Table 1 (Continued)

Indicators	Sub-Indicators	Description	Assumption	Reference
Physical Resources	Irrigation	↑ Number of Sources of irrigation	↑ Adaptive Capacity	Mondal, Jain, DeFries, Galford, and Small (2014)
	Ownership of farm implements/machine	↑ Number of useful farm machines owned by the farming household	↑ Adaptive Capacity	Ellis (2002)
	Access to vehicles	↑ Number of vehicles owned /rented by the farming household	↑ Adaptive Capacity	Arimi (2014)
	Farm ownership	Type of farm occupancy	Ownership means ↑ Adaptive Capacity	Defiesta and Rapera (2014)
	Nearness to the urban centers (i.e., market, government)	↓ Minutes of travel to the urban centers	↑ Adaptive Capacity	Yu, Zhu, Breisinger, and Hai (2013)
Financial Resources	Financial assistance from family members	↑ Amount of monetary assistance received by the household	↑ Adaptive Capacity	Defiesta and Rapera (2014)
	Sources of income from farming	↑ Amount of all sources of monthly income of the farming household from farming	↑ Adaptive Capacity	
	Sources of income from non-farming	↑ Amount of all sources of monthly income of the farming household from non-farming	↑ Adaptive Capacity	
	Monthly expenditure for farming	↑ Average monthly expenditure for farming	↑ Adaptive Capacity	
	Monthly expenditure for non-farming	↑ Average monthly expenditure	↑ Adaptive Capacity	Takeshima and Salau (2011)
	Value of farm animal units	↑ Number of farm animals owned and raised by the household	↑ Adaptive Capacity	
	Recipient of financial assistance/subsidy from the government	Whether the respondent has availed financial assistance or subsidy for farming from the government regularly or not	Higher assistance means ↑ adaptive capacity	
	Access to credit	Access to credit from 2009 to 2013	Formal credit means ↑ adaptive capacity	
	Access to new information regarding farming	↑ Number of medium to access new information regarding farming	↑ Adaptive Capacity	
Information	Recipient of technical assistance	If the farmer has consulted or has been regularly visited by an agricultural extension officer from 2009 to 2013	Technical assistance means ↑ adaptive capacity	Defiesta and Rapera (2014)
	Membership in farmers' organizations	If the respondent is a member of any farmers' organization	↑ Adaptive Capacity	Frank and Buckley (2012)
	Sources of climate information	↑ Number of sources accessed by the farmer about the climate information	↑ Adaptive Capacity	Defiesta and Rapera (2014)
	Sources of income	↑ Number of sources of income and employment of all the household members	↑ Adaptive Capacity	Umoh et al. (2013)
Livelihood diversity	Crops planted	↑ Number of crops planted	↑ Adaptive Capacity	Defiesta and Rapera (2014)
	Crops farm size	↑ Size of farm for every crop	↑ Adaptive Capacity	

Analytic Hierarchy Process (AHP)

AHP tool was used to assess how each indicator of adaptive capacity (human, physical, and financial resources, information, and livelihood diversity) contributes to the overall adaptive capacity level as perceived by the key informants. It is a multi-criteria decision-making method that models the complexity of decision problem, incorporating both quantitative and qualitative factors. It follows a process to derive the weights or priorities and synthesize the information to determine the relative ranking/scores of alternatives (Saaty, 1980). They were asked to select the most important indicator of adaptive capacity using pairwise comparison.

Normalization

To obtain consistent values and units of data, the adaptive capacity scores per indicator and sub-indicator calculated from the AHP were normalized by adjusting the values measured on various scales to a common scale. The normalization method, or the min-max approach, is as follows:

$$\text{Normalized } (e_i) = \frac{E_{\text{actual}} - E_{\text{min}}}{E_{\text{max}} - E_{\text{min}}}$$

where: E_{actual} = actual value for variable E
 E_{min} = minimum value for variable E
 E_{max} = maximum value for variable E
 thus, if $E_{\text{max}} = E_{\text{min}}$ then normalized (e_i) is set to 0.5

Chi-square was also used to determine the relationship between adaptive capacity level and adaptation practices of farming households.

Results and Discussion

Socio-Demographic Profile of Respondents

More than half (60%) of the respondents are male household heads. The average household size of families in the three barangays ranges from five to eight members (48%). About three-fourths (77%) of the household families are tenants while only 16% are owners of farmlands.

Effects of Climate Change to Farming Households

Farming households and key experts perceived flooding as the immediate effect of climate change. Flooding can cause soil erosion, especially in the upland, and depletion of resources such as soil and important organic matter. It can also cause crop damage resulting in lower farm productivity. While some materials are eventually deposited to the lowland areas providing soil nutrients, excessive deposition would cover suitable soil for rice farming as it is replaced by less suitable upland soils. Farmers also reported the changes in water quality

and quantity that affected the choice of crop to plant. Unlike in the past when they were only dependent on rice, some farmers have recently resorted to planting vegetables, such as mustard, Chinese cabbage, and string beans. Alternative crops or resources that are more resilient such as fruit trees and rattan were likewise considered.

Adaptive Capacity Indicators

The adaptive capacity indices of the farming households in Mabitac were identified as human resources, financial resources, information, physical resources, and livelihood diversity with the intervention of policies, institutions, and processes. The adaptive capacity scores were classified according to the levels of adaptive capacity (low, moderate, or high).

The adaptive capacity indicators were compared and weighted using AHP tool which showed the contribution of each of the indicator to the level of adaptive capacity. Figure 2 illustrates the different scores calculated for each adaptive capacity indicator and its sub-indicators.

Human resources obtained the highest weight (0.3087), followed by financial resources (0.2531), information (0.2202), physical resources (0.1615), and livelihood diversity (0.0566). This implies that human resources is the primary contributor to adaptive capacity of a farming household due to the importance of their farming experience and skills. According to Yang and An (2002), human resources can boost farmers' abilities both in selecting activities and performing agricultural operations. It is also significant for households in deciding how to allocate resources between agriculture and non-agriculture and it increases the technical skills and managerial ability of using input, such as high-yielding seed varieties (Huffman, 1977).

Livelihood diversity got the lowest weight (0.0566) since rice farming is mostly monoculture. According to Lyimo and Kalangawe (2010), livelihood diversity, inclusive of farming and non-farming activities, is vital in ensuring sustainability in a rural area. However, some find it hard to do due to years of traditional practices.

Sub-indicators

Human resources. The percentage of adults working in the farm got the highest weight (0.618) while diseases present in household got the lowest (0.0104) score. Thirty-two percent of the respondents have been farming for 10 to 20 years which contributes to their adaptive capacity because more experience gained and mastery of farming methods mean improved ability to respond to possible climatic changes. Twenty-four percent of the respondents were high school graduates. Ninety percent of the respondents attended farming or agricultural trainings, which also contributes to higher adaptive capacity since more exposure to farming trainings means higher adaptive capacity. Only a few number of respondents are exposed to diseases such as cough (34%) which is another contributor to adaptive capacity.

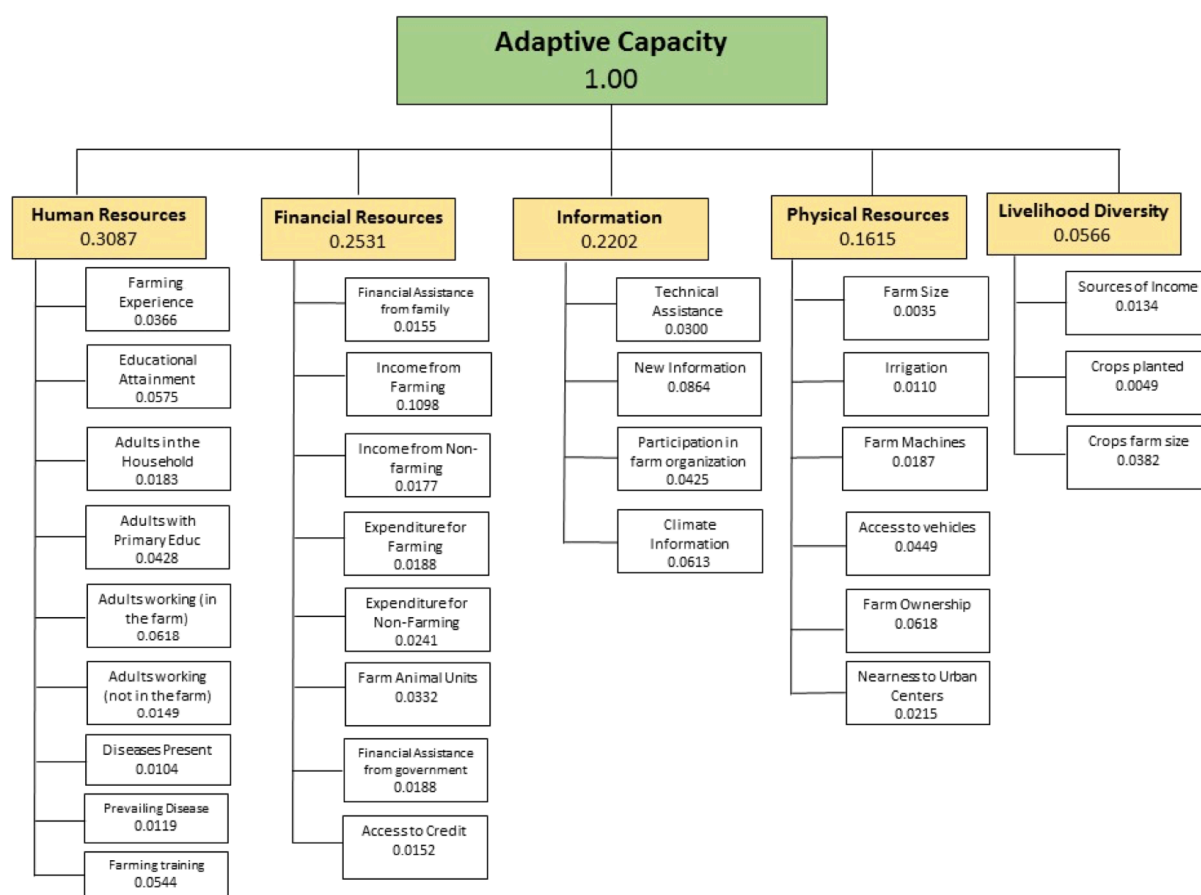


Figure 2. Analytic hierarchical tree of adaptive capacity indicators and sub-indicators

Financial resources. In the Philippines, the impacts of climate change are threats to the livelihood of the community especially in the field of agriculture (Penalba & Elazegui, 2013). Lack of financial resources limits adaptation options. Lack of money means lesser access to farming systems, technology, and opportunities like access to credit and remittances from family members.

About 41% of the farming households have a monthly income of PhP 5,001 to PhP 10,000 (USD 100 to USD 200). This means that most households have relatively high adaptive capacity. Majority (60%) indicated that they do not have income from non-farming activity such as working in offices, hence majority of the households have lower adaptive capacity. Respondents also stated minimal expenditure in farming because some resources needed by farming households were given for free by the owner as part of the tenancy agreement and/or by the LGU. Consequently, monthly expenditures for non-farming activities are high ranging from PhP 5,001 to PhP 10,000 per household, which includes food, electricity, school concerns, and others.

Although majority (69%) owned animals, most of these animals are pets (46%), while only 32% are farm animals. Due to this, most households have low adaptive capacity.

After natural calamities, farming households have no choice but to depend on the government's assistance. Among the respondents, 52% received financial assistance from the government which was mainly for the beneficiaries of 4Ps (Pantawid Pamilyang Pilipino Program), increasing the level of adaptive capacity.

Through credit sources, people are more able to afford the necessities and resources for farm inputs. Accordingly, 79% have access to credit, while the remaining 21% have chosen not to ask for credit because they thought they could not pay the loans in the long run or their money was enough. According to the experts' interview, some farming households who availed loans cannot pay on time. Thus, interests of the loaned amount are compounded, increasing the amount needed to be repaid. Since there are only a few number who do not have access to credit, there is also less number of households who have lower adaptive capacity.

Remittances and/or contribution from other family members add to one's financial resources. Only 29% of farming households had been receiving remittances ranging from PhP 500 to PhP 1,000 monthly. Majority of the households therefore have lesser assistance which means lower adaptive capacity.

Information. Access to new information received the highest weight (0.0864) among its sub-indicators. Access to information is important as it increases the probability of adaptation because farmers become aware of the steps they should and should not do. Majority (93%) have access to new and relevant information regarding farming, hence higher adaptive capacity. The most common source of new information is the Municipal Agricultural Office (MAO) and Department of Agriculture (DA) followed by television. Farmers are not accustomed to sharing what they know because they think that the other farmers already know the information. This is why farmers' organizations help the farmers in strategies and techniques in agriculture as well as in adaptation sharing.

Seventy-nine percent mentioned that they were members of organizations such as Dakila Lucong Irrigation Association (DALIA), Fisheries and Aquatic Resources Management Council (FARMC), Samahan ng mga Magsasaka ng Mabitac or Organization of Farmers in Mabitac, Pag-asa's Farming Organization, National Food Authority (NFA), National Irrigation Administration (NIA), and Agricultural Committee. The respondents who were members of farmers' organizations also gain new information from the membership such as new planting methods or strategies. Hence, majority of the households gain higher adaptive capacity in terms of information.

Technical assistance obtained the lowest weight (0.0300) because of its limited practice and accessibility. According to the Municipal Disaster Risk Reduction and Management (MDRRM) staff, technical assistance is possible but not in all areas because of the differences in context and nature of the region.

Physical resources. Farm ownership got the highest (0.618) while farm size got the lowest (0.0035) weight. Farm ownership is an important indicator as it translates to personal decision on what farming practices to implement to attain full productivity of the land. Results showed that 77% of the farming households were tenants. Most of the farmers share the resources with the owners including the risks and rewards.

Majority (82%) of the respondents have access to the irrigation system of NIA, while six percent still have rain-fed farms. In the study, 74% of farming households own farm equipment with hand tractor as the most common (22%). Most households have high adaptive capacity because of their high access and exposure to physical resources mentioned above.

Ownership of vehicles also has a significant role in farming as the distribution of harvested crops becomes easier. Accordingly, about 53% of the respondents own vehicles while 43% only rent. Owned vehicles were mostly tricycles (55%) and motorcycles (30%).

Most of the farms are near the main road. However, the travel distance from the farm to the marketplace (Siniloan Market) is 35 minutes and above. The travel time from the farm to the government and urban centers would take 11 to 15 minutes.

Due to a relatively longer distance of the farm from and to urban centers, most households have lower adaptive capacity.

Livelihood diversity. Only a few respondents have different sources of income. Most of the household income was derived from the farm (56%) while others have income from employment (20%), business (15%), or both (9%). Having diverse sources of income makes a specific household stable even when disaster and/or flooding occurs. Most of the farming household have limited livelihood diversity that contributes to their low adaptive capacity.

Levels of Adaptive Capacity

About 12%, 69%, and 19% of the respondents have low, moderate, and high adaptive capacity levels, respectively (Table 2). Majority of the farming households exhibited moderate level of adaptive capacity based on the AHP of their assets and resources.

Table 2. Adaptive capacity level of farming households in Mabitac

Levels of Adaptive Capacity	Frequency	Percentage (%)	Adaptive Capacity Scores (Range)
High	14	19	0.6490 - 0.5045
Moderate	52	69	0.5044 - 0.3600
Low	9	12	0.3599 - 0.2155
Total	75	100	

Information resources contribute the highest value for both the moderate and high adaptive capacity levels. The pentagram (Figure 3) shows that the main difference between those with low adaptive capacity level and those with moderate and high is the access to and use of new and significant information resources. The value of financial resources and livelihood diversity for households with high adaptive capacity is also significantly higher compared to those with moderate and low adaptive capacity. Those who have employment and business usually have higher adaptive capacity level. This shows that the low adaptive capacity level of farming households is mainly caused by low level of information resources, financial resources, and livelihood diversity.

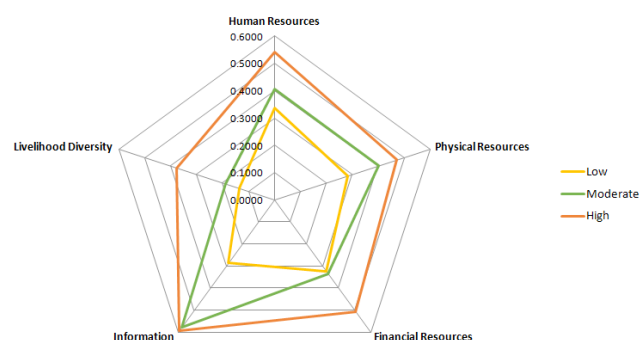


Figure 3. Pentagram of the farming households' adaptive capacity indicators' scores

The overall adaptive capacity level of farming households in Mabitac can therefore be increased by enhancing the human resources aspect through capacity building; improving the physical resources by providing necessary infrastructures such as irrigation and improved market access; and promoting livelihood diversity through diversification of crops and providing alternative sources of livelihood. Strong financial and information resources should be sustained and supported through increased access to credit and new information and technology.

Farmers' Adaptation Practices and LGU Activities

Adaptation practices of farmers in Mabitac include changing the cropping calendar (41%) particularly among those practicing rain-fed agriculture. Farm-level adaptation practices are helpful in coping with the impacts of climate change, but their effectiveness can be enhanced by institutional and policy support from the government (Asian Development Bank [ADB], 2009). Other practices such as crop rotation and additional farm inputs (fertilizer) aim at increasing productivity amidst climate change. Some farmers have already shifted from rice mono-cropping to crop diversification (e.g., mustard, Chinese cabbage, and string beans). Some are also venturing to fruit trees or tree-based production such as rattan.

The activities of the LGU regarding climate change adaptation include developing early warning systems; forming rescue teams and first responders; establishing the Local Disaster Risk Reduction and Management Council; conducting relief operations; providing trainings and seminars; distributing fertilizers and seeds after a disaster; implementing waste management; building river walls; maintaining irrigation; and distributing farming implements. These activities allow farmers to better facilitate adaptation within the household and farm levels.

Adaptive Capacity Level and Decision to Practice Adaptation

With regard to the relationship between adaptive capacity level and decision to practice adaptation, results of the study (Table 3) showed that there is no association between adaptive capacity level and decision to practice adaptation among the farming households in Mabitac. The high level of adaptive capacity does not guarantee that the farming households practice adaptation; in the same way, a low level of adaptive capacity does not necessarily imply that they do not practice adaptation. The relationship of adaptive capacity level with the number of adaptation practices/strategies employed by the different households likewise showed that there is no association between the two variables (Table 4). This agrees with the findings of Hogan, Berry, Ng, and Bode (2011) that the levels of adaptive capacity are non-determinants to adaptation practices among farming households.

Table 3. Adaptive capacity levels vs. decision to practice adaptation among farming households in Mabitac, Laguna

Decision to Practice Adaptation	Adaptive Capacity Level			Total
	Low	Moderate	High	
To practice adaptation	3	30	8	41
Business as Usual (BAU)	6	22	6	34
Column Totals	9	52	14	75

Table 4. Number of adaptation practices employed by farmers vs. their adaptive capacity level in Mabitac, Laguna

Decision to Practice Adaptation	Adaptive Capacity Level			Total
	Low	Moderate	High	
1	2	14	5	21
2	1	15	3	15
3	0	1	0	1
4	0	1	0	1
5 and above	0	3	0	3
Column Totals	3	30	8	41

Conclusions

Majority (69%) of the farming households have a moderate level of adaptive capacity resulting from better access to information, and human and financial resources. The low adaptive capacity level of farming households is mainly caused by low level of information resources, financial resources, and livelihood diversity. These can serve as guide in designing interventions that seek to increase the adaptive capacity of farming households aiming to reduce their vulnerability to increased flooding caused by climate change.

There is no association between the level of adaptive capacity and the decision to practice adaptation, including the number of adaptation practices employed by the farming households. Even households with low adaptive capacity level can practice adaptation in the same way as those households with moderate or high adaptive capacity. There are other intervening factors that affect the households' decision to either adapt or not adapt to the impacts of climate change such as the mono-cropping and other traditions of the farmers as well as some policies within the community.

Recommendations

For the Local Government Unit of Mabitac

The adaptive capacity of farming households in Mabitac can be enhanced by improving their livelihood diversity, human

capital, and physical resources. Towards this end, development interventions such as crop financing and insurance, climate-field school, and crop diversification program need to be pursued to increase the adaptive capacity level of farming households.

The adaptive capacity and adaptation insights gained from this study can be integrated into Climate and Disaster Risk Assessment (CDRA) that will form part of the different local plans such as Disaster Risk Reduction Management Plan (DRRMP), Local Climate Change Action Plan (LCCAP), and Comprehensive Land Use Plan - Comprehensive Development Plan (CLUP-CDP). Furthermore, the lessons learned can also be used in prioritizing adaptation strategies of the LGUs particularly on scaling-up existing adaptation practices and increasing adaptive capacity of households through capacity building and provision of support services for agriculture.

For Further Research

For further research, the sub-indicators of adaptive capacity used in this study can be expanded and extended to incorporate and test other factors affecting one's adaptation, such as community capacity, experience, and behavior. The complexity of adaptation practices and their effectiveness can also be further studied to understand the rationality of adoption.

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