

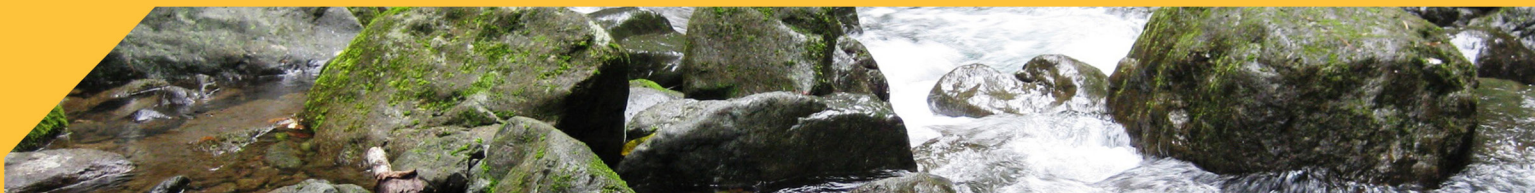
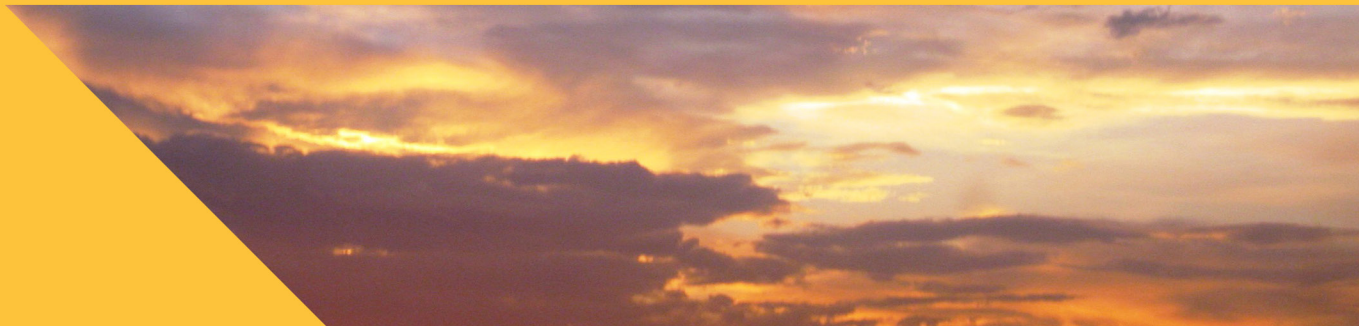


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Climate, Disaster and Development (CDD) Journal is a project of the Oscar M. Lopez Center for Climate Change Adaptation and Disaster Risk Management Foundation, Inc. (OML Center), a non-stock, non-profit organization based in the Philippines. The Center is dedicated to promoting 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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Aims and Scope

The CDD Journal aims to publish peer-reviewed, original research on all aspects and intersections of climate, disaster 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.

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Harvesting and Managing Rainwater Using Collapsible Rubber Tanks

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Abstract

Rainwater harvesting (RWH) is an existing technology proven to be effective in reducing pressure on water resource, yet often overlooked by planners, engineers, builders and decision-makers as a viable alternative for supplying water to households and businesses while reducing stormwater runoff in urban settings. RWH tanks are commonly made of concrete, plastic, stainless steel, ferrocement or earthen jars. In this study, the use of collapsible rubber tanks (CRTs) as an alternative storage container for RWH was explored. The study was conducted in Barangay La Mesa, Calamba City, Philippines. This barangay uses rainwater for domestic use. Bladder or pillow, rectangular and square-type designs were installed, tested and monitored in terms of ease of use and handling. The portability of the tank makes it an attractive option in an urban setting where space is limited and land is expensive. A CRT with 500-800 liter capacity can be used by a five-member household for three days for their basic water needs, and comes at an affordable price range of Php 3,500-5,000 (USD 65-95). With proper handling and maintenance, the CRT can be a good alternative for rainwater storage and serve other purposes. It can be useful in hard-to-reach areas particularly during emergency situations and relief operations.

Keywords: rainwater harvesting, collapsible rubber tank, climate change adaptation, El Niño

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Introduction

The Philippines is endowed with rich natural resources, including water. The average annual precipitation (amount of atmospheric moisture that fall back to earth by gravity) is about 2,348 mm. The total exploitable water resources are about 146 km³, 126 km³ of which is renewable surface water and 20 km³ is renewable groundwater (Food and Agriculture Organization [FAO], 2016).

Despite having these resources, accessibility to reliable and safe water supply remains a privilege not everyone can afford. Provision of water has been among the many problems constraining economic growth, good health, and overall development. In addition, water problems have become varied and complex; these include: inadequate surface water supply, over drafting of groundwater, flooding, sedimentation, pollution and degradation of drinking water (Klee, 1991).

Among the available water sources, groundwater has been highly exploited. In 2009, the country's total freshwater withdrawal was estimated to be 81,555 million cubic meters (MCM), of which 82% was for agricultural purposes (including 754 MCM of aquaculture, 8% of which is for domestic consumption and 10% is for the industry (FAO, 2012). With the current rate of groundwater utilization, more pressure is expected from the stressed resource, given the further increase in population and economic activities the country is experiencing. On one hand, voluminous rainfall tends to go to waste and its potential use is not maximized. During extreme rainfall, flooding may occur and can result in disastrous events. When this happens, the provision of sufficient amount of safe and potable water can be very difficult, thereby affecting hygiene and sanitation of stricken communities. The result can further lead to disease outbreaks of life-threatening cholera, typhoid, dysentery, and some forms of hepatitis.

The country also needs to prepare for the El Niño phenomenon, which is commonly associated with reduced rainfall that lead to dry spells, droughts, and stronger typhoons (FAO, 2017). Dry spells and drought are periods when rainfall is lower than the expected average amount over a longer period (World Meteorological Organization, 2006). According to the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA), the latest El Niño to hit the country was in 2015-2016 and an estimated total damage and crop production loss of PhP 4.7 billion (USD 87 million) was recorded.

These water-related problems are worsened by the impacts of climate change that lead to extreme events, and part of the plausible solution is harvesting and storing of rainwater. Rainwater harvesting (RWH)

captures, conveys, stores, and releases green water (the portion stored in soil and potentially available for uptake by plants) in-situ. Today, this technology has been proven effective in flood/disaster mitigation and aids in food and water security, environmental rehabilitation, and climate change adaptation. RWH, as a simple and stand-alone system, can be considered as one of the best practices in water resource management. In recognition, the country has enacted the Republic Act (RA) No. 6716 or the Rainwater Harvesting Act of 1989, which mandates the construction of water wells and rainwater collectors in all barangays¹. This RA is currently being revived by the Department of Public Works and Highways (DPWH). In 2009, Davao City passed a City Ordinance to reiterate proper harvesting, storage and utilization of rainwater. This ordinance sought to mainstream the use of RWH systems across the city. It also mandates that all new building construction should have provision for RWH.

Literature citing research work and undertakings on collecting rainwater for drinking purposes in the country are available, including those of Filipino inventor Dr. Antonio Mateo (Mateo, 2012). In Capiz Province, rainwater tanks were made of wire-framed ferrocement costing PhP 3,500-6,500 (USD 67-125) for a 2-4 m³ tank. Before RWH was introduced in Capiz in 2002, households had the perennial problem of water scarcity during the six-month long dry season.

Common methods and types of collecting rainwater include the use of small impounding reservoirs. In residential areas, a more acceptable storage is the use of tanks. These tanks are mostly made of corrugated steel and enclosed metal, concrete, wood, fiberglass, clay, and polyethylene or polypropylene plastics. Such tanks are durable but rigid and require space. They can also be expensive unless recycled containers are used. In urban areas where space is cramped and limited, finding proper placement for these types of tanks can be difficult.

Such predicament gave rise to the idea of using a collapsible rubber tank (CRT), a geotextile fabric-made tank that is both flexible and foldable. The CRT, which has various uses for different conditions, could be the solution to a long-standing problem of water shortage. As a result, this research was conceptualized to specifically develop, fabricate and test various CRT designs, and influence water users and decision-makers to strongly support RWH.

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

Methodology

The research was conducted for one year and five months (June 2014 to October 2015) to adequately test the designed prototype during the rainy months. To test the effectiveness of the tank, prototype fabrications were installed in selected demonstration sites and responses were collected from 12 chosen participants.

Selection of Pilot Test Area and Cooperators

In pilot testing the applicability of CRT, an urban area was considered as an important criterion due to its high water demand and overly crowded and cramped residential spaces. Calamba City (Figure 1) was selected as the pilot site, being a center of trade in Laguna and in Southern Tagalog, and categorized as a highly urbanized area, thus with potential water deficit. Calamba is one of the most populous cities in the Philippines, with an average annual growth rate of 2.99% (2010 to 2015) and a total population of 454,486 (as of 2015). Demographic data and physical profile were gathered from different concerned offices, such as the Office of the City Planning, Office of the Engineering and Infrastructure Development Department, Calamba City Disaster Risk Reduction and Management Council (CDRRMC) and the Public Order and Safety Office (POSO).

It is worth-noting that during the ocular survey and preliminary inspection, it was observed that the residents were already practicing RWH with drums or plastic containers (Figure 2) because of inadequate supply of tap water.



Figure 1. Location map of Barangay La Mesa, Calamba City, Laguna

After selecting Barangay La Mesa, Calamba City as the demonstration area, meetings with the barangay officials and co-operators were undertaken to discuss the objectives and expected outputs of the research, and the role of each of the research partners. Research



Figure 2. The typical water storage are plastic drums and containers

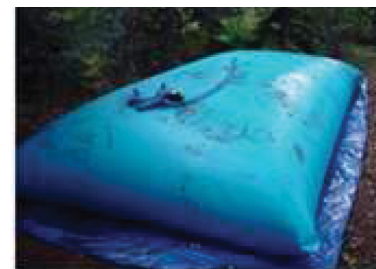
co-operators were selected using the following criteria: house has existing gutter and spout, and has space for CRT installation, and homeowner is willing to cooperate in data monitoring.

Design, Fabrication and Testing of CRTs

The tank designs for testing (bladder, pillow and square-type) (Figure 3) were initially patterned after existing collapsible tanks used in other countries.



(a)



(b)



(c)

Figure 3. Types of CRT designs: pillow or bladder (a and b); and vertical rectangular (c) (Waterplex, 2014; Portable Tanks, 2014; Interstate Products Inc., 2014)

The fabricated CRTs were tested and inspected for defects, such as leaks and tears, before installation. Modifications were later made to consider durability, ease of local fabrication, ease of use and handling, and ease of maintenance by the co-operators. While dependent on scale, the RWH system is relatively simple to use and potential users can easily be trained on how to install the tanks.

In determining the size of the CRT, information on average annual rainfall, roof catchment size, installation area, and water demand were necessary.

Annual Average Rainfall

This is the recorded and measured rainfall over an area. Records are usually available from PAGASA weather stations around the country. This information is necessary in computing for the potential available water to avoid oversizing the tanks. "As a general rule, rainfall should be over 50 mm/month for at least half a year or 300 mm/year (unless other sources are extremely scarce) to make RWH environmentally feasible" (Hattum & Worm, 2006). In the case of the Philippines, having an annual average rainfall of 2,400 mm provides an ideal condition for RWH.

Roof Catchment Size

It is the area of the roof for collection and discharge of rainwater. The roof should have gutters connected to a spout that will discharge to the tank.

Installation Area

It is the available area to install the tank. Ideally, the area should be accessible to the spout to minimize long gutter extension and to a canal/drainage/open land for discharge if rainwater will not be used.

Water Demand

It is the intended use of rainwater and water usage. In the Philippines, a person's average water consumption per day is 120 liters (The Philippine Environment Monitor, 2003).

Below is an example of how to compute for the potential available rainwater in a given area for a five-member family living in a building with a roof surface area of 100 m², and using the average annual rainfall in the area (e.g. Calamba City) of 2,400 mm, with a per capita consumption of 120 liters/day in an urban area:

Potential Available Water = Annual rainfall (in mm) x roof area (m²) x co-efficient of runoff from roof

Potential Available water

$$= \text{Area of catchment (A)} \times \text{annual rainfall (R)} \\ \times \text{Runoff Coefficient (C)} \\ = 100 \text{ m}^2 \times 2.4 \text{ m} \times 0.85 \\ = 204 \text{ m}^3 \text{ (204,000 liters)}$$

Water requirement per day

$$= \text{number of family members} \times \text{per capita requirement} \\ = 5 \times 120 \text{ liters/capita/day} = 600 \text{ liters day}$$

Based on this computation, a family of five will need approximately 3,000 liters for five-day duration of usage. A rainfall intensity of 53 mm/hr with T=2 years in a 1-hour rainfall duration can collect 5.3 m³ of water. Therefore, a 5,000 liter-capacity RWH tank can be easily filled up by a rainfall of 53 mm/hr intensity given a 100 m² roof area in less than an hour.

Estimated Runoff Volume

The surface runoff volume was computed using the Rational Method Equation: $Q_{\text{runoff}} = cIA$, where Q is the Peak discharge, c is the runoff coefficient (for roofs ranges from 0.75-0.95), I is the rainfall intensity, and A is the drainage area. This method is used to determine the peak discharge from drainage basin runoff. This was aided using ArcGIS software and images taken from Google Earth.

The water bill records of the selected 12 co-operators (Table 1) were gathered to determine the average amount of water consumption from the tap by each household. It is also the basis for computing their potential savings for using rainwater.

Table 1. List of co-operators from Barangay La Mesa, Calamba City

Cooperator	No. of household members	Water bill (PhP)
Cooperator 1	5	400
Cooperator 2	5	155 – 200
Cooperator 3	7	200 – 250
Cooperator 4	5	200 – 250
Cooperator 5	4	155 – 200
Cooperator 6	5	200 – 250
Cooperator 7	4	155 – 200
Cooperator 8	3	155 – 200
Cooperator 9	5	155 – 200
Cooperator 10	4	155 – 200
Cooperator 11	-	-
Cooperator 12	6	300

Monitoring and Evaluation

Regular visits, meetings, and focus group discussions were conducted to observe how the tanks were being used and maintained by the co-operators. These activities allowed the co-operators to immediately report to the research team the problems encountered in using the tanks. The number of interested adopters and inquiries were also recorded. Comparative cost analysis between CRTs and other types of rainwater storage tanks was also undertaken.

Results and Discussion

In general, water issues in Calamba City exist in various forms akin to other regions of the country. Access to water is not equal; some barangays have adequate supply all throughout the day, while others experience interrupted supply. Disparity can be observed more during the dry season, when no alternative source in the form of rain is available. Barangay La Mesa, the selected demonstration site in Calamba City, is one of those barangays with limited access to water.

A local cooperative is servicing the area for piped water supply. According to the residents, the tight water delivery schedule from the existing water utility forced them to look for alternative sources, one of which is the use of RWH containers. This is usually done during the rainy months, when rainfall is abundant. However, other parts of the city, especially those in the low-lying areas near Laguna Lake, experience flooding during the rainy days.

Potential Runoff Reduction by Rainwater Harvesting

The city's climate falls under Type 1, which has two pronounced seasons: dry from November to April

and wet during the rest of the year. Rainy months for Calamba City fall under June to September, and the average annual rainfall is 1,965.9 mm from 2000 to 2012 (Figure 4). Using Gumbel's theory of distribution, the computed maximum rainfall intensity is 305.86 mm/day for a rainfall event with a 24-hr duration and a 20-year return period. The data used in the computation came from PAGASA-Agrometeorological weather station in the University of the Philippines Los Baños (UPLB).

The estimated surface runoff for Barangay La Mesa was 264,473.33 m³/day. Currently, it has 2,545 households and a total population of 11,836. Assuming that the barangay would collect 10% of the total runoff, the amount of rainwater that could be harvested would have a volume of 26,447.33 m³/day.

Using the basic water requirement of 120 liters/capita/day (Philippine Environment Monitor, 2003), the volume of rainwater collected can sustain 220,394 people for a day. With this, the total population of Barangay La Mesa can be sustained for 18 days even without using the piped system. This was computed by dividing 264,473.33 m³/day by the population requirement of 1420.32 m³/day at 10% collection.

Using PAGASA's color-coded warning system and the area of each of the barangays in Calamba City, the amount of rainwater that could be collected was computed and summarized in Table 2 (next page). Assuming that all households, establishments, and facilities will install a RWH unit, runoff will be lessened and flooding can be delayed.

CRT Design Testing and Installation

Three designs were tested: the pillow type, the rectangular pillow type, and the vertical tank type (square-type). The first tank design tested for material strength and functionality was the pillow type (Figure 5), whose dimensions were as follows: height of 0.46 m., width of 1.52 m, and length of 2.13 m. The tank has inlet and outlet faucets, wherein the latter serves as a pressure control valve. The estimated average capacity of the tank is 1,100 liters. Once filled, the tank can be left to overflow to avoid the build-up of pressure, while leaks and defects found on the tank can be repaired using patches of similar fabric and a solvent for sticking. This design is suitable mostly to buildings and houses with large spaces, where it can be placed at the rear end or side of the house. With an approximate weight of 1.1 tons when filled with water, this type of large tank can be very heavy and would require a mechanized lifter

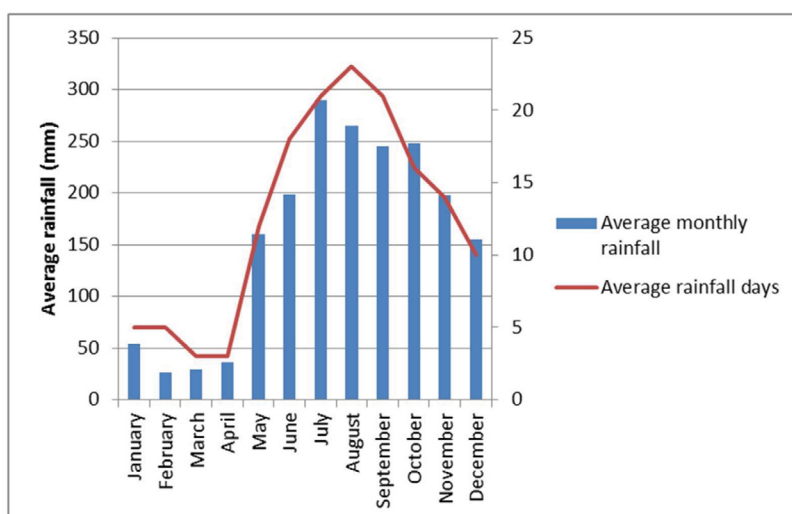


Figure 4. The average rainfall distribution in Calamba City from 2000 to 2012 (World Weather Online, 2015)

Table 2. Runoff estimate in the different barangays of Calamba City, Laguna using PAGASA's color-coded warning system

Barangay	# of household	Runoff estimate (m ³ /hr) for the next 3 hours		Barangay	# of household	Runoff estimate (m ³ /hr) for the next 3 hours	
		Yellow warning	Orange warning			Yellow warning	Orange warning
Bagong Kalsada	711	19093.5	38187	Mabato	152	25029	50058
Banadero	1530	23512.5	47025	Majada-Labas	1112	22675.5	45351
Banlic	1784	35316	70632	Makiling	1615	59193	118386
Barandal	995	23202	46404	Mapagong	1063	35892	71784
Barangay 1	1413	6961.5	13923	Masili	771	6286.5	12573
Barangay 2	1721	4239	8478	Maunong	453	35928	71856
Barangay 3	948	8307	16614	Mayapa	4693	19242	38484
Barangay 4	696	969.75	1939.5	Paciano Rizal	2571	20749.5	41499
Barangay 5	1351	4792.5	9585	Paligon	1377	3289.5	6579
Barangay 6	526	7407	14814	Palo-Alto	2285	28435.5	56871
Barangay 7	542	18274.5	36549	Pansol	2337	84379.5	168759
Batino	269	16065	32130	Parian	4354	14355	28710
Bubuyan	358	19665	39330	Prinza	859	15282	30564
Bucal	2440	44376.75	88753.5	Punta	755	42120	84240
Bunggo	819	51264	102528	Putting-Lupa	370	48780	97560
Burol	383	23800.5	47601	Real	2969	21253.5	42507
Camaligan	210	11452.5	22905	Saimsim	1184	23040	46080
Canlubang	11753	411921	823842	Sampiruhan	1751	16659	33318
Halang	1468	26221.5	52443	San Cristobal	2706	19957.5	39915

**Figure 5.** The pillow tank at full capacity**Figure 6.** Filling of rectangular pillow tank (left); Pressure valve releasing excess water from the tank (right)

to transport to areas needing water. However, its high volume capacity is more practical for use in hard-to-reach areas in preparation for emergency and relief operations, but would have to be transported to intended evacuation centers when empty in order to ease the mobility.

The second design (Figure 6) was another rectangular pillow tank with the following dimensions: height of 0.19 m, length of 4.36 m, and width of 0.74 m. The

estimated capacity of the tank is 600 liters. In addition to the inlet and faucet, a water release outlet was added to the tank to avoid overfilling that may result in tearing. Similar to the pillow tank, it can be used for various purposes in different types of housing and building structures. However, it proved to be more difficult to balance during transport, especially when filled with water, and finding a space for this type is more laborious due to its longer length.

The third design is a square-type tank (Figure 7) with the following dimensions: height of 1.83 m and square base of 0.76 m with an estimated capacity of

1,057 liters. One problem encountered with this type is its inability to support itself when filled with water. While the size can be reduced to achieve its form and serve its purpose with minimal difficulty in handling, a better option would be to provide a frame to support its body (Figure 7a).

The vertical rectangular type (Figure 7b), with a dimension of 1.22 m in height, 0.7 m in length and a width of 0.46 m, was also tested. The estimated capacity of the tank is 300 liters. It is smaller than the square-type but with similar need in terms of support. To address this, a metal casing was also fabricated to support the tank, which added cost to the production. In the design and fabrication of CRT, economic viability and flexibility were important considerations.



Figure 7. Testing of (a) vertical square-type tank and (b) vertical rectangular type tank

The fabrication of CRT was customized for the individual co-operator. Table 3 shows the locally fabricated CRTs installed in the field. These tanks (Figure 8), excluding the vertical tank, need a simple stand for a more convenient water withdrawal.

Material and Fabrication

Flexible bladder tanks are made with high-resistance, waterproof polyvinyl chloride (PVC) material, similar to that of rubber boots (Figure 9) and are welded with high frequency (HF) soldering techniques. It



Figure 8. Common types of tanks tested in the site were bladder and square-type CRT



Figure 9. Common materials for making the tank include high resistance PVC e CRT

Table 3. Type of installed CRTs in the field (refer to Figures 6-8 for the sample prototypes)

Tank type	Dimension (empty) L x W x H	Dimension (filled) L x W x H	Capacity	Units	Cost (PhP)
Water-bed type 1	1.52 x 0.61 x 0.45	1.75 x 0.9 x 0.46	750	9	3,500
Water-bed type 2	1.83 x 0.61 x 0.45	2.00 x 0.9 x 0.46	810	4	3,800
Square-type	1.10 x 1.10 x 0.40	1.34 x 1.34 x 0.46	820	1	5,000

is important that the seam can withstand the water pressure. Repeated testing and modification of the design and process eventually resulted in a tank that can withstand water pressure and resist bursting. However, continuous improvement of the design and materials used should be done for the technology to have a competitive commercial advantage.

Tank Components, Installation and Mobility

The tank has an inlet, a faucet, and a pressure release hole/valve through which water can automatically spill out when the tank reaches full capacity. Since

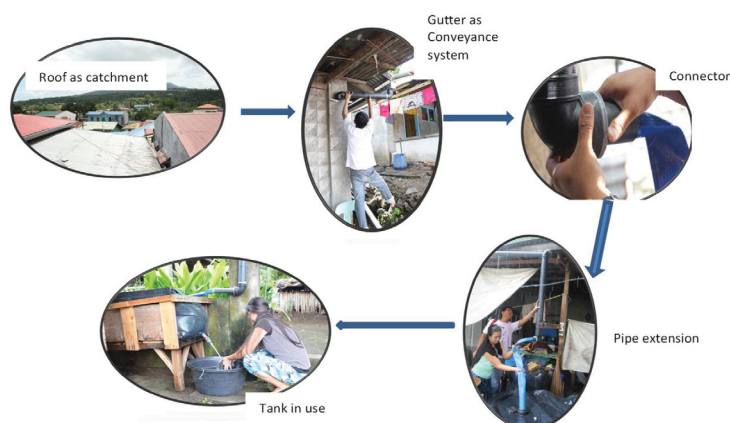


Figure 10. Schematic diagram of CRT installation

the tank is made of a geomembrane textile material, it can be easily installed (Figure 10) or dismantled for safekeeping when not needed. The CRT may be placed in any unused or vacant space, such as at the basement, roof of the house, or under any structure near a spout. The CRT can be considered as the new-generation tank.

Before installation, gutters and spouts must be inspected to ensure they are properly connected to the roof. Simple measures should be observed and followed, which include:

1. Collapsible water tanks should be water-tight and should be placed in a containment structure (for vertical tank) or a ground mat (for horizontal tank) for support and protection.
2. The tank should be placed in a leveled area, free from materials that may damage the tank. It must be placed in a location allowing easy access for maintenance. Lastly, the tank should be placed near a canal or open land for drainage or recharge, in case the collected water will not be used.
3. The tank should be labeled with "RAINWATER" to inform that it contains rainwater and is not suitable for drinking.
4. When rainfall intensity is high and water is expected to overflow, the pressure release valve should be opened to prevent overfilling the tank.
5. Rainwater entering the CRT must pass through a

filtering mechanism (e.g. screen) to prevent entry of debris into the tank. Gutters should be cleaned out once in a while to reduce debris accumulation and spout clogging.

6. Roof and gutters should be repaired if there are any damages. Roof material should not be made from asbestos or wood, and painted with substances harmful to human.
7. Branches extending above the roof should be pruned.



Figure 11. A wooden stand is an optional feature to elevate and secure the tank

Tank Frame or Stand

As seen in Figure 8, placing tanks on the ground causes difficulty in fetching water due to its low elevation, which hinders water from flowing freely. Depending on the user's preference, a stand may be needed to elevate the tank, of which any design may be used as long as it can securely hold the tank. On the other hand, a frame is optional (Figure 11).

Monitoring Process

Twelve tanks were installed and monitored in the research area. Weekly monitoring to assess the functionality, ease of use, and manageability of the tanks was also an important step, wherein the problems that were encountered, such as leaks, were timely resolved.



Figure 12. One of the co-operators filling the tank with rainwater

The co-operators were able to continuously fill the tanks during the rainy months (Figure 12). According to the users, the tank with a capacity of at least 700 liters could be filled to its maximum in less than 2 hours, given an average rainfall of 204.70 mm/month. The rainwater collected in the CRT was used primarily for laundry, flushing, cleaning of the house, watering of plants, and washing of vehicles. One account from the co-operators said that their average monthly bill of around PhP 400 to PhP 550 was reduced to PhP 300, and their dependence on water utility was lessened.

When asked whether they would still use the CRT if available commercially, the co-operators gave a generally favorable and positive response. To further improve the tank's lifespan, which was an observable limitation, discussions on proper maintenance were mentioned.

Economic Considerations

The cost of the locally fabricated CRT with a minimum capacity of 600 liters ranges from PhP 3,500-5,000 (mat and frame not yet included). According to a hardware, the price of a stainless steel tank with a capacity of 800-1,000 liters is between PhP 15,000-19,000, while the price of a polyethylene tank with a capacity of 600 liters is at least PhP 8,200. The fabrication cost of CRT is cheaper compared to the cost of rigid tanks. However, proper comparison in terms of life span and durability cannot be concluded yet, as the locally fabricated CRT is still under test and research. However, it can be noted that rigid tanks can be used from 8 to 14 years and based on the experiences of long-time users abroad, CRTs have a warranty of approximately 5 years (Portable Tanks, 2014). It is important to consider certain factors that affect the lifespan of a tank, mainly: fabrication materials, application, environment, and external influences such as temperature and exposure to heat.

The recommended average water use in the Philippines is 120 liters/capita/day (Philippines Environment Monitor, 2003). Assuming that the average number of household members is five, the monthly consumption of a household is 18,000 liters or 18 m³ on the average. The cost of the first 10 m³ is PhP 183 and PhP 19.20/m³ for the succeeding 10 m³. The water consumption cost is PhP 336.60 (2% tax included). With this current water rate in Calamba City, monetary savings from using the collapsible tank is minimal. However, continuously drawing underground water for consumption and utilization can lead to its depletion, which poses a problem. In Australia, the government gives rebates to their residents when using RWH tanks to lessen dependency on groundwater.

Minimizing the Effects of Drought

The country has experienced one of the most severe

El Niño phenomena on record in late 2015 to June 2016. Another incident was in 1998, when 70 % of the country was affected and PhP 3 billion (USD 56.9 million) (Rodrigo, 2016) worth of crops were damaged. In such instances, the agricultural sector took a serious hit, which led to low production of staple crops such as rice. The reduced rainfall did not only lead to dry spells and droughts, but the phenomenon also resulted in stronger typhoons. While El Niño is to be expected, with sufficient planning and support, its effects can be minimized. Before the onset of the dry season or drought event, rainwater can be collected and stored in tanks and can serve as water source for household use and other purposes whenever there is lack of water supply on dry days.

Other Observed and Realized Benefits

The residents of Barangay La Mesa, Calamba City were using RWH to augment the water supply from the local water utility. They use any available container to store rainwater, but the rising dengue cases in the area prompted the officials to prohibit rainwater collection using containers without cover. Since the CRT is covered, entry of dengue-carrier mosquitoes was prevented and breeding in the tanks was reduced, if not stopped. As a result, the project was endorsed by the barangay officials and the pilot-testing of the CRT in the area was readily welcomed by the residents as an alternative to their usual water containers.

Overall, the CRT has a very good potential for rainwater storage, whether it be in drought-stricken or flood-prone urban areas. This can be attested by the increasing number of invitations from various local governments units for seminar on CRT.

Conclusion and Recommendations

Using CRT for harvesting rainwater is a newly explored endeavor. The CRT has high potential for wider use and commercialization, especially in a tropical country like the Philippines, where occurrences of drought, flooding and tropical diseases associated with stagnant water are common. Wider dissemination and adoption of this type of technology should be supported, along with continuous improvement through research and partnership with an industry capable of fabricating the CRT. This will ensure a design that will be commercially available and affordable for ordinary citizens. Moreover, policy support and advocacy to strengthen and mandate RWH for sustainable water supply should be implemented and adopted. The case of the DPWH reviving and revisiting RA 6716 mandating the development of rainwater collectors is a good initiative in showcasing water conservation in the Philippines. Through this effort, total reliance on water utility systems for all types of water demand can be minimized, if not totally avoided, which can

then lessen the continuous usage and depletion of groundwater to give it time to recharge. Moreover, adoption of RWH can also prevent or delay flooding.

While the pilot-testing of fabricated CRTs have demonstrated good acceptability among the co-operators, continuous improvement on the following should be done:

- tank design
- durability
- use of locally available materials
- filtration system
- water quality assessment and
- application in agriculture, emergency and relief operations

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Simulating Impacts of ENSO and Climate Change on Sugarcane Production in Negros Occidental Province, Philippines

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Abstract

The Philippines is a major exporter of sugarcane, ranking 9th in global production. By 2024, the government aims to increase the country's sugar productivity by 27% (from 60 t/ha to 75 t/ha) by consolidating rainfed farms and investing in irrigation. Although it is generally known that climate change affects crop production and food security, there is little understanding of how climate change and El Niño-Southern Oscillation (ENSO) events will impact production targets and future irrigation requirements. Crop models are cost-effective tools that can help policy makers and food planners to adapt to the changing weather and rising CO₂ emissions; however, the methods used in crop modeling need to give robust, reproducible, and transparent estimates before they are used with confidence by food authorities. This study simulated the crop responses of sugar-growing farms in Negros Occidental, Philippines to ENSO events and mid-century climate using the AquaCrop model. The point model was extrapolated and converted into provincial scale to help agricultural planners in their decision making. The upscaled model was validated using yield data from 2005 to 2017. The climate change projections show that cane yield would increase from 5% to 30% by 2050 due to wetter summers. Rainfall from December to March explains 82% of the variability in the simulated annual yields, indicating higher irrigation returns. This study demonstrated the utility of crop models and upscaling methods, which can guide future climate change assessments at larger scales.

Keywords: AquaCrop · sugarcane · Negros · ENSO · climate change · irrigation

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Introduction

Sugar is a major export crop of the Philippines. Globally, the country ranks 9th in sugarcane production, 8th in terms of area planted, and 37th in yield, which averages 74 tons per hectare (t/ha) (Zhao & Li, 2015). The industry directly employs 630,000 workers and five million workers indirectly (Development Bank of the Philippines [DBP], 2015). The annual production is highly variable (coefficient of variation [cv] = 11.94 t/ha), and growth is relatively flat, averaging 0.25 t/ha per year (Food and Agriculture Organization [FAO], 2013). About 79% of the country's sugar production in 2017 came from Negros province (Philippine Statistics Authority [PSA], 2018).

Large modern farms in the Philippines operate more efficiently, generating yields up to 100 t/ha. Smallholder farms (areas with ≤ 5 ha), on the other hand, comprise 80% of the total number of farm holdings in the country. Most smallholder farms are rainfed, with average yields of 60 t/ha. Espino (2017) cited that the 83 sample farmers from Negros Occidental had shown yields of 80.6 t/ha and 62.5 t/ha for irrigated and rainfed farms, respectively.

The Sugar Industry Development Act of 2015 (Republic Act [RA] No. 10659) aims to increase rainfed farmers' yield by 27% (from the current 60 t/ha to 76 t/ha) by 2024 through consolidating small farms and investing in irrigation. However, the impacts of climate change (e.g., changing rainfall patterns, higher temperatures, and future crop responses) pose a challenge toward this goal. Accordingly, the Philippine government has pushed the issue of climate change impacts and variability on food supplies and irrigation infrastructure to the center of the country's food policy and research. Disruptions in these systems due to climate change and El Niño-Southern Oscillation (ENSO) events can trigger shortages and significant economic losses. Unfortunately, most irrigation infrastructures in the country are designed without considering the impacts of climate change.

Crop models are inexpensive tools that help researchers to understand how climate can affect plant growth and development. So far, the crop models that have been developed have relied on the physical concepts of soil, plant water, and climate interactions. Crop models can simulate the responses of locally grown crops to a range of environmental conditions, including climate change, particularly when these models are combined with weather generators that are downscalable to represent local weather.

Developing models to show the impacts of climate change on food-producing regions in the Philippines can help researchers to better understand the range of threats and the corresponding adaptation options available to farmers. Methods used in crop modeling need to give robust, reproducible, and transparent estimates before

food authorities can use them with confidence. However, researchers are not able to maximize the use of crop models when doing regional assessments because the data collection procedure for such assessments is expensive and time consuming. To the best of our knowledge, no large-scale impact assessments of the sugarcane grown in the Philippines have been made using crop models.

In this study, we developed an approach for modeling sugarcane production at a provincial scale using less rigorous data sources while still satisfying the minimum data requirements for calibrating and validating the model. Negros Occidental was chosen as the sample province because agricultural surveys are regularly conducted in this province. Moreover, official records are updated regularly and are accessible through the PSA website. Such advantages would allow future researchers to further refine the model and validate official figures, or vice-versa. Crop models would also complement existing survey methods and facilitate the decision making of the provincial agricultural office and the Sugar Regulatory Administration as they prepare their development plans for the sector.

This study aims to demonstrate how a crop model can be used to assess the present and mid-century impacts of ENSO and climate change on sugarcane growth and productivity in Negros Occidental province, Philippines. Likewise, the research aims to recommend the optimal irrigation strategies for sugar production in order to address the foreseen impacts of climate change.

Related Studies

The existing physiological studies involving chamber experiments provide information regarding the effects of high temperature, elevated CO₂, and drought stress on cane plant processes (de Souza et al., 2008; Inman-Bamber, 1994; Singels et al., 2000). These studies have demonstrated that sugarcane productivity increased due to higher photosynthetic rates and improved water-use efficiency, which resulted from higher CO₂ concentrations. Likewise, the results have helped researchers to identify the parameters that can be used in crop models in order to simulate plant responses to increasing CO₂ levels (Singels et al., 2000).

A number of climate change modeling studies generally agree on the positive effects of the future climate on cane yields (yield increase of about 4%–29%). Singels, Jones, Marin, Ruane, and Thorburn (2013) projected 4%, 9%, and 20% increases in cane yields in Australia, Brazil, and South Africa, respectively. Other studies reported increases of 15%–29% in Brazil by 2050 (Marin et al., 2013); 15–25 t/ha increases in South Africa by 2055 (Schulz & Kunz, 2010); 16% increase with CO₂ effects (compared with the +5% without CO₂ effects) in Swaziland by 2050 (Knox, Rodriguez, Nixon, & Mkhwanazari, 2010); 7%–15% increases in irrigated

cane yields by 2100 in South Africa (Jones, Singels, & Ruane, 2013); and 5%–6% increases with CO₂ effects by 2050 in Australia (Sexton, Everingham, Inman, & Stokes, 2014). On the other hand, other studies have shown negative effects. Singh and El Maayar (1998) reported 20%–40% reduction in cane yield in Trinidad and Tobago, whereas Cheero-Nayamuth, and Nayamuth (2001) cited 32%–57% decreases in Mauritius. These studies, however, did not consider the effects of CO₂ on photosynthesis and transpiration (Singels et al., 2013).

Other studies reported mixed results. In Australia, Biggs, Thorburn, Crimp, Masters, and Attard et al. (2013) reported that climate change has a “weak” effect when yield increases and a “strong” effect when yield decreases. The variations in the modeling results may be due to the differing general circulation models (GCMs) used in the climate projections and to the varying crop model responses to the effects of elevated CO₂ (Biggs et al., 2013; Vanuytrecht & Raes, 2011; Vanuytrecht, Raes, & Willems et al., 2011).

Meanwhile, several studies point to the beneficial effects of elevated CO₂ conditions on the increased photosynthesis and reduced stomatal conductance, which improve starch accumulation and water-use efficiency (Ainsworth & Roger, 2007; Vu & Allen, 2009a, 2009b; de Souza et al., 2008). Nevertheless, most models agree on the significant impacts of water variability on soil moisture, especially in rainfed farms.

Crop models are upscaled from field to regional scale because food authorities need science-based and data driven evidence to support their decision making. Point-based crop models that are originally developed, calibrated, and tested for field scale applications are increasingly used for larger areas and longer time periods (Marin & Carvalho, 2012; Cheero-Nayamuth & Nayamuth, 2001). Upscaling methods, ranging from the simplest method (using a single point) to more sophisticated nested models, have already been classified (van Oijen et al., 2009; Ewert et al., 2011).

However, upscaling creates uncertainty in the model’s output due to limitations in data quality, availability, and aggregation approaches, thereby constraining their use in regional studies (Hansen & Jones, 2000).

Coarse-weather, soil, and cropping system data are used for climate assessments that rely on crop yield simulations because finer spatial high-quality data are absent. Thus, pragmatic shortcuts are required to achieve full terrestrial coverage (Grassini et al., 2015). These shortcuts are rarely evaluated to reproduce yield data using high-quality and measured data, such as those obtained from government statistical records. Without validation, yield estimates using coarse-scale data sources can seriously distort results, thereby decreasing their usefulness to inform regional or national policies for agriculture. Protocols to overcome data limitations

have been developed as part of global yield gap studies (van Wart 2012, van Bussel 2015, & Grassini, 2015). Accordingly, these protocols are applied in this study for climate change assessments.

Materials and Methods

Study Area Description

Negros Occidental is a province in the Philippines located in the Negros Island region. It is known as the “sugar bowl of the Philippines”, producing more than half of the nation’s sugar output. The landscape consists of alluvial plains and hilly and mountainous areas. A mountain range lines the eastern part of the province that forms the basis of the border shared with another province, Negros Oriental.

The climatological records from the La Granja station of the Philippine Atmospheric, Geophysical, and Astronomical Services Administration (PAGASA) show that the average minimum and maximum temperatures in Negros Occidental from 1987 to 2003 are 22.1 °C and 32.8 °C, respectively. The rainy season starts in May to December, whereas the dry season starts from January to April. Annual rainfall is 2,642 millimeters (mm), with cv = 0.15. Rainfall records show an increasing trend of 11 mm per year during the period 1975–2016.

Point models refer to a plant’s response to a combination of cultivar, climate, soil, and farm management interactions. Accordingly, we developed a point model to represent the farms in the Araal–Najalin–Marayo watershed. This watershed is a 19,535-hectare-wide sugar-growing region surrounding the La Granja-PAGASA station in La Carlota City and supplies the La-Carlota sugar central milling district (Figure 1).

Upscaling Method

The choice of upscaling methods would depend on the desired changes in the extent, coverage, or resolution of the crop area being studied. The simplest method is the point extrapolation method, which has been used in earlier studies that assessed the impacts of climate change on crops (Rosenweig & Party, 1994). We chose this method as it demands less data, has low computing time, and has high reusability, i.e., low required knowledge to reuse the method (Ewert 2011). Using the point extrapolation method, we extrapolated and then converted the Araal–Najalin–Marayo watershed point model into provincial scale in accordance with the published guidelines (Grassini et al., 2015; van Wart, Kersebaum, Peng, Milner, & Cassman, 2013; van Bussel et al., 2015). Accordingly, the guidelines for upscaling recommend the following:

1. Selecting homogeneous locations with minimum coverage of about 40%–50% of the total harvested

area in order to account for the largest proportion of total production for a chosen scale (e.g., province or country);

2. Choosing weather stations with sufficient geospatial coverage and data quality; and
3. Identifying the dominant soil type and averaging farmer practices in each location where yield is simulated (van Wart et al., 2013; van Bussel, 2015).

In this study, we selected the sugar-growing areas in Negros Occidental based on the expansive homogeneous topography of its lowland cane-growing areas. In place of crop maps, we used the land area of the province as proxy for harvestable area. The land area within a buffer zone of 50 kilometers (km) of fixed radius around the La Granja PAGASA station represents 40% of the total area of the province (Figure 1).

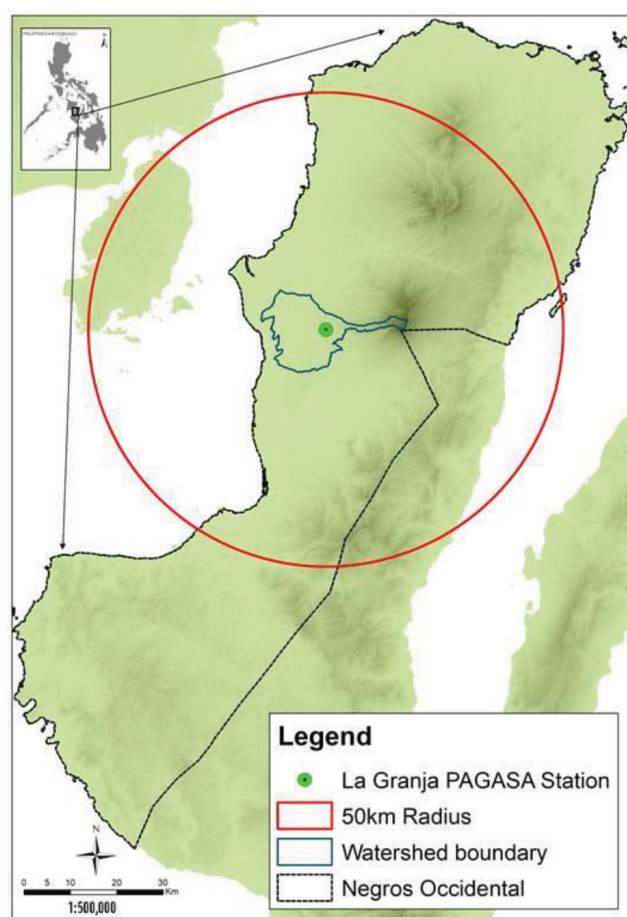


Figure 1. Map of the La Granja PAGASA Station

AquaCrop Model

We used the AquaCrop model¹ to simulate the growth and development of sugarcane crops under typical management practices in La Carlota City, Negros Occidental province. The year 2010 was used as the current baseline and year 2050 as the future climate scenario. The model simulated the impacts of elevated CO₂ concentration and higher temperature on photosynthesis, transpiration, and phenology.

AquaCrop requires input files for the daily maximum and minimum temperature, rainfall, and evapotranspiration (ET_o). The baseline for rainfall consists of a 41-year time series of historical monthly rainfall (1975–2016) and 12-year daily rainfall records (2004–2016), which were collected from the La Granja-PAGASA station. Since the daily temperature records from La Granja station were not available, the 23-year daily record of Iloilo City (which is 56 km away from La Carlota City) from 1987 to 2010² was used.

AquaCrop sets CO₂ concentrations at 388 parts per million (ppm) to represent the 2010 baseline. The mean monthly solar radiation, which can be obtained from climatological normals, was converted into ET_o using the ET_o calculator.³ The ET_o calculator follows the Penman–Monteith method described in the study of Allen, Pereira, Raes, and Smith (1998).

Model Calibration and Validation

Crop models that cover large spatial areas require high-quality input data to account for the variations within a given agronomic landscape. These high-quality data are not available for most parts of the Philippines. Thus, we collected the data for calibration from different sources, including the PAGASA weather records, farmer interviews, PSA website, independent reports, and installed pre-calibrated model parameters. Farmers were interviewed to collect data on the planting dates, growing period to maturity, and cultivar types. Based on the soil sampling reports of Evangelista (2017), the soil type at the study site is predominantly clay loam.

¹ This can be downloaded at <http://www.fao.org/nr/water/AquaCrop.htm>.

² The data are available and can be downloaded from the National Oceanic Atmospheric Administration website (<https://www.ncdc.noaa.gov/cdo-web/datasets/GHCND/locations/FIPS:RP/detail>).

³ This can be downloaded from the FAO website.

The Aquacrop model was calibrated by setting the yield⁴ values for rainfed farms to 60 t/ha and irrigated rainfed farms to 80 t/ha; both values are based on the yield estimates of Espino (2017). The ratio of rainfed to irrigated farms by harvest area was assumed to be 80:20, which corresponds to the proportion of smallholder (< 5 ha) to large farms (≥ 5 ha). The composite yield from both areas was calculated using their weighted contribution by harvest area.

Clay loam is the dominant soil texture in the study area, with field capacity and wilting points set at 16% and 8% by volume, respectively. The modeling error was minimized by adjusting soil fertility loss to 20%. AquaCrop does not model nutrient fluxes but uses a biomass loss adjustment factor to account for nutritional effects from nutrient-deficient treatments (Hsiao, Heng, Steduto, Rojas-Lara, & Fereres, 2009). Based on the information gathered from the farmers' interviews, the planting month was set to May as this is the period when rainfed small-scale farmers wait for the onset of rains. The initial condition assumes that soil moisture is at field capacity. The coefficients for growing degree days, water use productivity, and ETo crop factors were derived from pre-calibrated default values that comes with AquaCrop for sugarcane (de Souza et al., 2008; Singels, Jones, & den Berg, 2008).

The model was validated using the PSA reports on fresh cane biomass production from 2005 to 2016 for Negros Occidental (PSA, 2018). The model skill and the simulated versus the observed values were evaluated using the normalized root mean square error and r^2 scores.

Normalized Root Mean Square Error

Normalized root mean square error (nRMSE) values that are close to zero mean that the differences between the simulated and observed yields are small. This further indicates that there is little systematic deviation or bias in the entire data set, and that the data set expresses precision and reliability of the simulation for observed estimation points. The performance of the model is *excellent* when the nRMSE is less than 10%, *good* if it is greater than 10% and less than 20%, *fair* if it is greater than 20% and less than 30%, and *poor* if it is greater than 30% (Nyang'au, Mati, Kalamwa, Wanjogu, & Kiplagat, 2014). The equation is expressed as

$$nRMSE = \sqrt{\frac{\sum_{i=1}^n (Si - Oi)^2}{n}} \cdot \frac{100}{O}$$

where:

- Si = number of simulated yields from the point model represented by farms in the Araal–Najalin–Marayo watershed,
- Oi = number of observed (measured) yields taken from the PSA provincial yield data for the years 2005–2016,
- n = number of observations, and
- $\bar{O}$ = mean value of Oi .

Coefficient of Determination

The coefficient of determination (r^2) is the regression sum of squares divided by the total sum of squares (SST). It is expressed as

$$r^2 = 1 - \frac{\sum_i (yi - fi)^2}{\sum_i (yi - \bar{y})^2}$$

where:

- y_i = observed data point,
- f_i = regression value, and
- $\bar{y}$ = mean of the data points.

The coefficient of determination (r^2) measures the goodness-of-fit of a model or how well the regression line approximates the real data points. An r^2 score close to 1 indicates a good fit of the model to the data.

Coefficient of Variation

Interannual and monthly rainfall variabilities were measured using cv , which can be expressed as

$$cv = \sigma / \mu$$

where σ is standard deviation and μ is the mean.

Irrigation Water Use Efficiency

The irrigation water use efficiency (IWUE, t/ha per 100 mm) can be expressed as the fresh cane biomass produced ($Y_{irr} - Y_{rain}$, t/ha) per unit of irrigation water applied (W_{irr} , 100 mm):

$$IWUE = \frac{Y_{irr} - Y_{rain}}{W_{irr}}$$

Simulating the Impacts of ENSO

We simulated the interannual cane yields from 1975 to 2016 while assuming that May is the planting month. The annual anomalies (departure from average values) were analyzed and correlated with the ENSO episodes for 1988, 1993, 1998, 2003, 2010, and 2015. Intra-annual yields were simulated and averaged by planting month. Monthly yield anomalies were analyzed with respect to monthly rainfall intensity falling during the course of the

⁴ In this paper, "yield" refers to fresh stalk biomass or cane biomass.

growing season.

The rainfall intensity uses the PAGASA categories for *above normal* (>1.2), *near normal* ($0.81-1.2$), *below normal* ($0.41-0.8$), and *way below normal* (<0.4). Rainfall intensity scores of 4, 3, 2, and 1 were assigned to each rainfall category in descending order. The scores were averaged for the four-month period from December to March to arrive at the rainfall intensity index for the period. The higher the index, the higher the rainfall intensity for the four-month period. The indices were then correlated to the annual percentage yield anomalies for the study period.

Future Climate Projections

Multi-model ensembles, when compared to single GCMs, can draw on the strengths of different GCMs and provide better estimates of the range of uncertainty behind the climate projections. Accordingly, 16 GCMs derived from the *5th Assessment Report of the Intergovernmental Panel on Climate Change* were evaluated in terms of how close they can predict the observed monthly values for the 2010 baseline period. Four of the best-fitting GCMs were selected based on the lowest nRMSE and highest r^2 scores for temperatures and rainfall. The selected GCMs were then used to project future climate and crop productivity. The simulations were limited to the mid-century as uncertainties increase when projecting beyond 2050.

In each of the GCM selected, the MarkSim weather generator produced ten-year replicates of daily weather files for five time slices, i.e., 2010 (control), 2030 (short-term), and 2050 (medium-term) for both representative concentration pathways (RCP) 2.6 (best case) and RCP 8.5 (worst case) scenarios.

The projected values were corrected for bias from the raw GCM outputs using the “delta method” (Graham, Andreasson, & Carlsson, 2007; Weiland, van Beek, Kwadijk, & Bierkens, 2010; Wilby et al., 2004; Tabor & Williams, 2010). The “delta method” uses the differences between baseline and projection periods for temperature and rainfall, as shown in Equations [1] and [2], respectively.

$$x_{cor} = x_o + \mu_p - \mu_b \quad [1]$$

$$x_{cor} = x_o + \mu_p / \mu_b \quad [2]$$

where:

x_{cor} = bias-corrected data in the baseline period;

$x_{o,i}$ (1, 2, ..., 25) = observed data in the baseline period;

b, p , and, o = simulated data in the baseline period, projection period, and observed data, respectively;

μ_p / μ_b = change factor for precipitation; and

$\mu_p - \mu_b$ = change factor for temperature.

The change factors were then plotted using box plots in order to quantify the uncertainty generated by the ensemble. The median change factors were applied to the historical baseline by adding the delta values to the observed temperature and by multiplying the ratio changes by the observed precipitation and ETo.

Simulating Potential Impacts of Climate Change

The bias-corrected weather files were read into the AquaCrop simulations. The yield by planting month was simulated for each month for both the baseline and projection periods. This required 960 runs ($40 \text{ years} \times 12 \text{ months} \times 2 \text{ time periods}$). In each time period, the box and whiskers were plotted to each planting month for biomass, growth cycle day, net irrigation requirement, transpiration, and water productivity (WPET).

The impact of CO_2 fertilization on cane crop was investigated for the 2050 projection period by running AquaCrop. The first scenario involves increased CO_2 from 388 ppm to 468 ppm, whereas the second scenario maintains CO_2 levels at 388 ppm (*No CO_2 scenario*). The *No CO_2* scenario simulates the impacts of increased CO_2 on yield and also the effect on yield if the CO_2 fertilization effect does not occur. Subsequently, the significance of the difference between the ensemble medians of projected periods and the baseline period was tested using students' t-test, with the threshold set at $p < 0.05$.

Results and Discussion

GCM Fitting and Bias Correction

We selected 4 GCMs out of the 16 GCMs available in MarkSim based on the model's ability to project climate scenarios for the 2010 baseline period. Accordingly, all GCMs had nRMSE scores for the monthly maximum and minimum temperatures ranging from 0.04 to 0.06 (excellent). Meanwhile, the nRMSE scores for predicting the monthly rainfall for the baseline period varied widely, ranging from 0.25 to 0.67 (poor). The r^2 score of the predicting median monthly rainfall values range from a high 0.86 to a low 0.19. The top four GCMs selected based on the highest to lowest r^2 scores are BCC-CSM1_M, CSIRO-Mk3-6-0, GISS E2-H, and GFDL-ESM2G (see Table 1).

Climate Projection

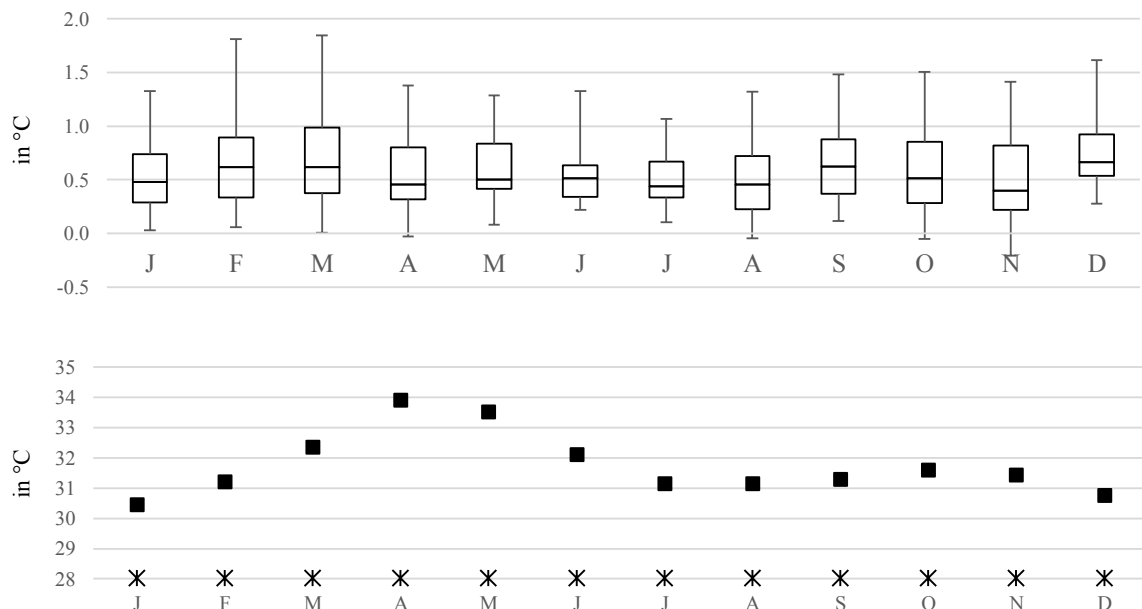
All four models agree on the projected temperature increases, with an average increase of 0.75 °C by 2050. Likewise, all of the values are significant at $p < 0.05$. The highest temperature increases are projected in February and May, whereas the lowest are in November, December, and January (not shown). The standard

deviation (σ) of the daily maximum and minimum temperatures are 1.6 °C and 1.1 °C, respectively, based on the daily temperature records of the PAGASA Iloilo station (1987–2010). The projected increase of 0.75 °C is close to the upper limit (0.8 °C) of the historical daily maximum temperatures.

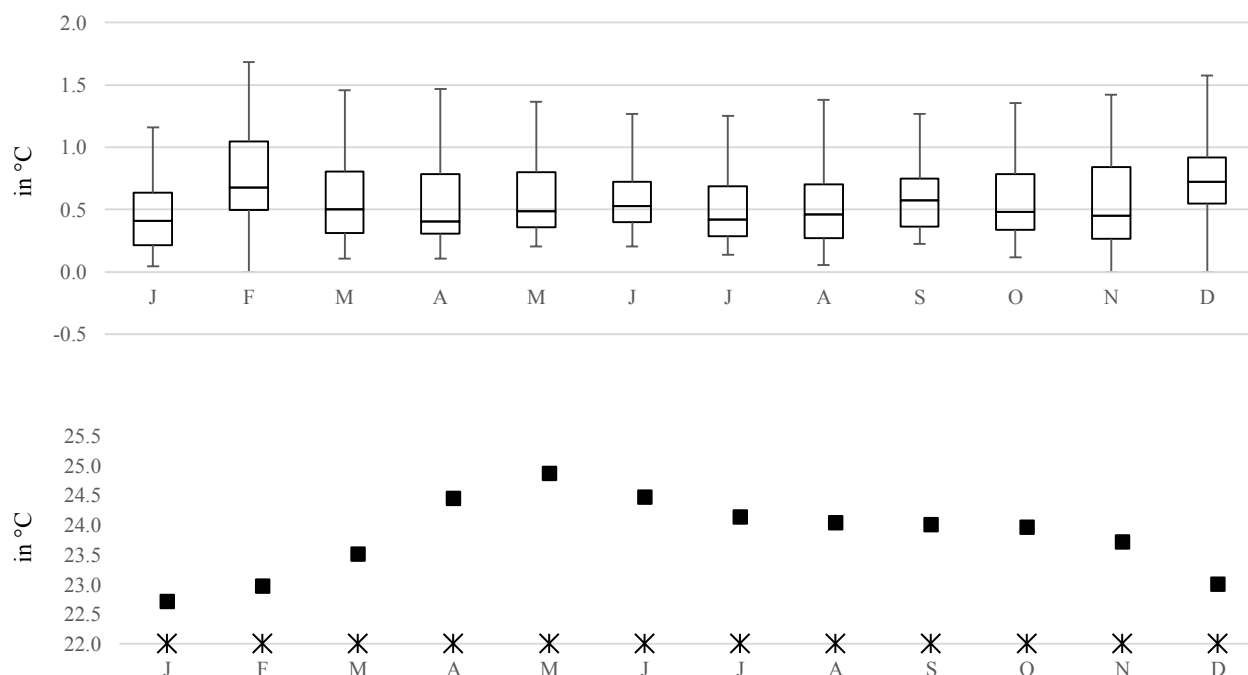
There is no apparent agreement on the change in rainfall in the GCM projections. The boxplots of the monthly precipitation change factors show wider variations from January to March ranging from 0.5 to 3.2. This result is consistent with the wide rainfall variability experienced during these months. The median monthly values for these months range from 1.2 to 1.4, which implies wetter summers. Little change is projected for the rest of the year. The estimated changes in March and May are significant at $p < 0.05$. Figures 2(a) to 2(c) show the multi-model box plots of projected changes in maximum and minimum temperatures and rainfall.

Table 1. GCMs selected for this study

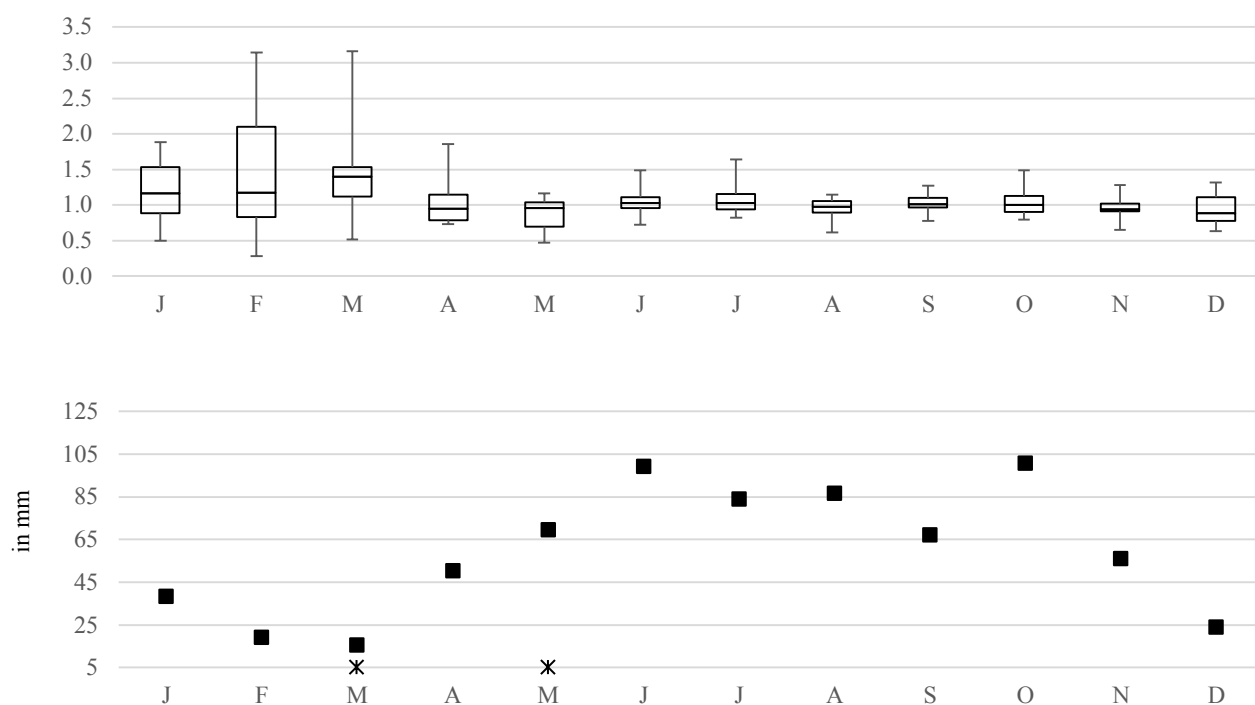
Model	Institution	Resolution, Lat° × Long°	Reference
BCC-CSM1_M	Beijing Climate Center China Meteorological Administration	2.8125 × 2.8125	Wu (2012)
CSIRO-Mk3-6-0	Commonwealth Scientific and Industrial Research Organization Queensland Climate Change Centre of Excellence	1.875 × 1.875	Collier et al. (2011)
GISS-E2-H	NASA Goddard Institute for Space Studies	2.0 × 2.5	Schmidt et al. (2006)
GFDL-ESM2G	Geophysical Fluid Dynamics Laboratory	2.0 × 2.5	Dunne et al. (2012)



(a) Upper: Box plots of monthly change factors for maximum temperature by 2050. Lower: Monthly average maximum temperatures, PAGASA-La Granja station, 1975–2003. Box plot represents 25th, 50th, and 75th percentile values. Whiskers represent maxima and minima.



(b) Upper: Box plots of monthly change factors for minimum temperature by 2050. Lower: Monthly average minimum temperatures, PAGASA-La Granja station, 1975–2003.



(c) Upper: Box plots of monthly change factors for rainfall by 2050. Lower: Monthly average rainfall, PAGASA-La Granja station, 1975–2003.

Figure 2. Multi-model box plots of projected changes in maximum and minimum temperatures and rainfall.

Notes. Figures with * refer to values that are significant at $p = 0.05$, one-tailed t-test.

Evaluating PAGASA Climate Forecasts by 2050

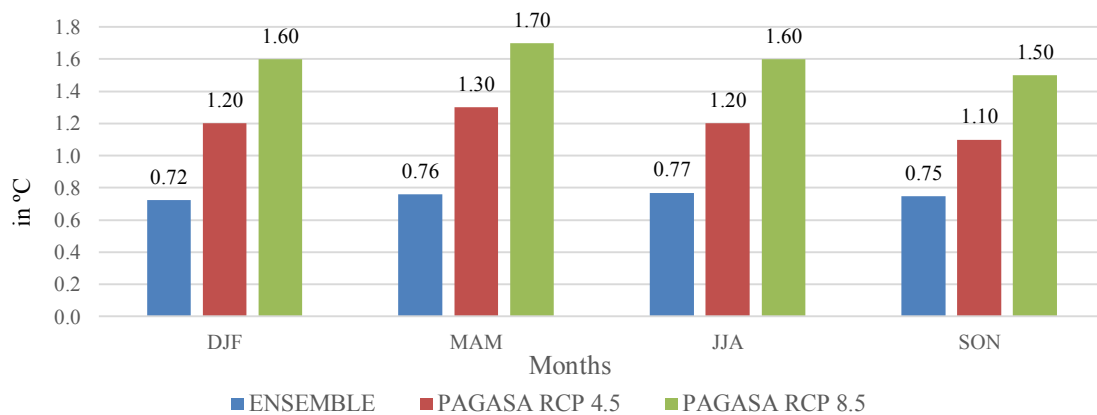
The PAGASA forecasts of 1.2–1.5 °C temperature increases in Negros Occidental by 2050 are twice higher than the model ensemble findings of 0.75 °C increase [Figure 3(a)]. Although the ensemble projections are lower, its values are closer to the national trajectory of 0.1 °C per decade or 0.4 °C by 2050 (PAGASA, 2018). The PAGASA annual rainfall forecasts by 2050 are 10% higher than the present baseline, albeit they still fall within one standard deviation of historical variability. The simulations show no significant trends in future annual rainfall (not shown).

There is also no agreement with regard to seasonal rainfall. The median ensemble forecasts for rainfall agree on the direction in only one of the four PAGASA quarterly scenarios [Figure 3(b)]. In the rainy months of June to November 2050, the PAGASA forecasts range

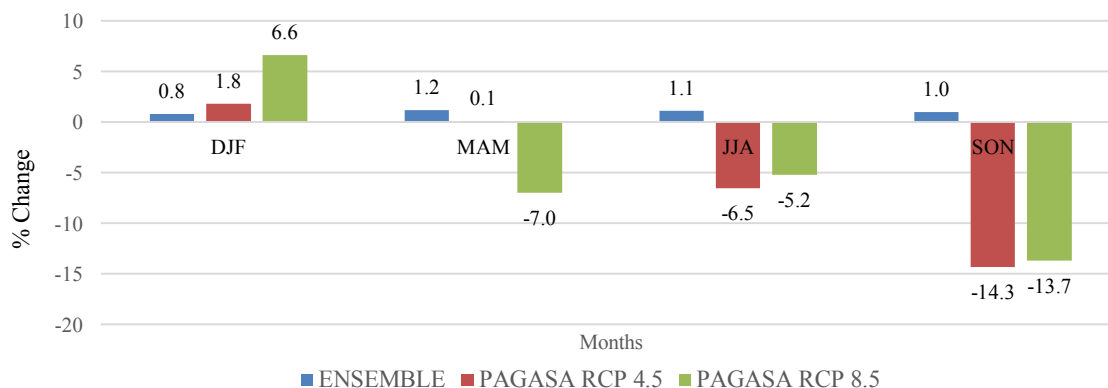
from –5.2% to –14.3%, which means that there would be lesser rains during these months. In the months of March to May, findings show small increases, whereas the PAGASA projections show decreases of –7.0% (worst case scenario) to 0.1% (no change). Lastly, the study shows a small increase (0.8%–1.2%) from the baseline in the months of December to February, as compared with the PAGASA data at 2%–6% increases.

There was good agreement between the simulated and observed yields after calibrating the crop parameters against the independent data (see Table 2).

The validation data consist of 12-year production data (2005–2016), which were downloaded from the PSA (2018) website for Negros Occidental province. The statistical indices (nRMSE = 0.07, excellent) support the good performance of the model.



(a) Temperature mean forecasts against the PAGASA forecasts, 2050, Negros Occidental



(b) Rainfall forecasts against the PAGASA forecasts, 2050, Negros Occidental

Figure 3. Projected increase in mean temperatures and rainfall by 2050.

Note. DJF = December, January, February. MAM = March, April, May. JJA = June, July, August. SON = September, October, November

Table 2. Parameters entered into AquaCrop

Parameter	Value
Attainable yield (fresh biomass, nonlimiting water and fertilizer)	80 t/ha
Actual yield, rainfed farm (assuming May planting)	60 t/ha
Plants per hectare	133,000
Ratio of rainfed to irrigated land areas	80:20
Soil texture	Clay loam
Field capacity (% volume)	16%
Saturation point (% volume)	36%
Permanent wilting point (% volume)	8%
Soil fertility loss	20%
Water productivity	30 g/sqm
Growth stage	
DAP to recovered transplant	10 days; 148 GDD
DAP to 95% maximum canopy cover	71 days; 1,257 GDD
DAP to maximum root depth	67 days; 1,188 GDD
DAP to start of early senescence	337 days; 6,039 GDD
DAP to harvest	371 days; 6,631 GDD
Corresponding FAO stages	
Initial stage	32 days
Canopy development	39 days
Mid-season stage	266 days
Late season stage	34 days

Note. DAP = days after planting. GDD = growing degree days (in °C)

Except in 2008 when the model overpredicted the yield values, the predicted values for the rest of the years fall within one standard deviation (11.9 t/ha) of the PSA data (Figure 4).

The production anomalies from the PSA data and the crop simulations were plotted on a scatter plot. The regression line, fitted to the points, showed fair to good correlation, with $r^2 = 0.68$ (see Figure 5). The AquaCrop model, as proxy for rainfall, explains 68% of the variation in Negros Occidental cane production. This is considered good, seeing that provincial statistics account for many other factors aside from rainfall, e.g., varying farmer practices, effects of pest infestations, and damages from flooding.

ENSO Impacts

El Niño and La Niña events represent opposite extremes in a complex, naturally occurring climate cycle known as the ENSO. This condition occurs when the surface air and water temperature in the equatorial Pacific deviate from the normal temperature. In the Philippines, El Niño is associated with high temperatures and severe dry spells. El Niño may be preceded or followed by La Niña, which is characterized by heavy rains, severe typhoons, and flooding.

Table 3 presents the monthly rainfall records of the PAGASA from 1975 to 2016, categorized by rainfall intensity class. *Below normal* (in yellow) and *way below normal rainfall* (in red) records most often fall from January to April, but may extend earlier to December and November. Severe El Niño events occurred in 1988, 1998, 2010, and 2015. Conversely, La Niña occurred in 1989, 1999, 2008, and 2011.

The interannual cane production of Negros Occidental from 1975 to 2015 was simulated using the AquaCrop model. Figure 6 shows the simulated percentage yield anomaly by planting year or the departures from the 45-tons-per-hectare average within the study period. The highest yield losses, ranging from 15% to 17%, were simulated for the El Niño years 1991–1992, 1997–1998, 2002–2003, and 2009–2010. The higher positive yield anomaly of 32%–34% coincided with those of the La Niña years, i.e., 1998, 1999, 2007, 2010, and 2011.

El Niño tends to have greater effect on rainfall during the summer months than during the rainy season. The regression analysis shows that the rainfall intensity index scores from December to March have positive relationship ($r^2 = 0.81$) with the simulated yield anomalies (Figure 7).

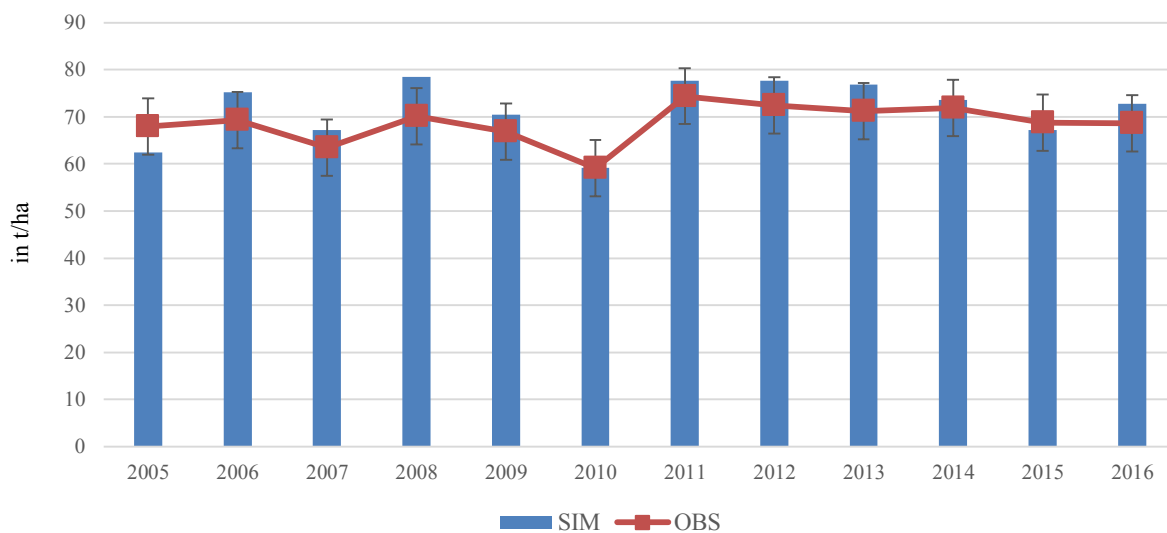


Figure 4. Simulated and observed yield data, 2005–2016

Note. Error bars are one standard deviation (11.9 t/ha) from the annual historical yields.

Source of basic data. PSA (2018)

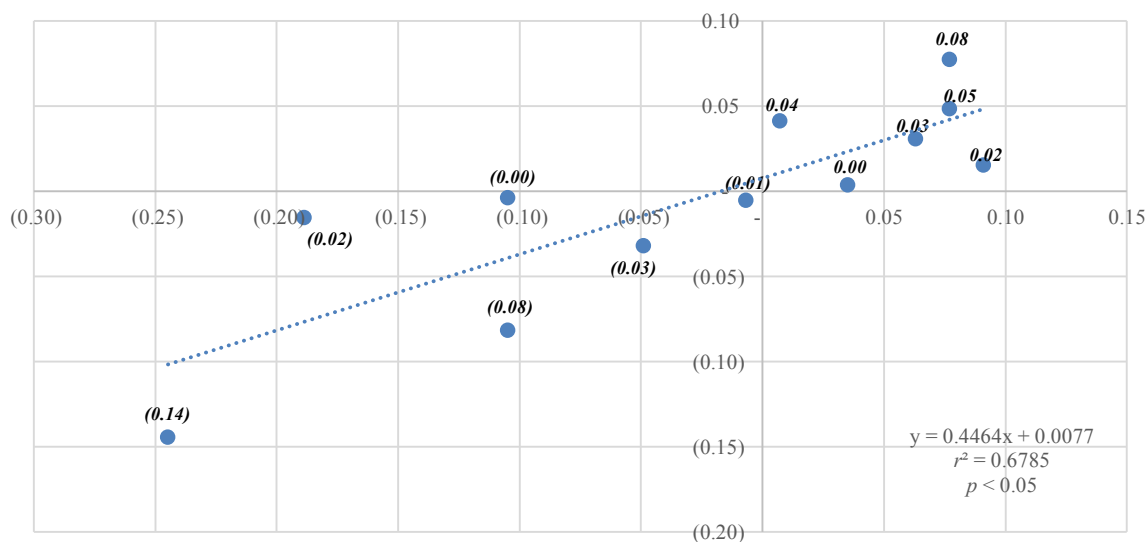


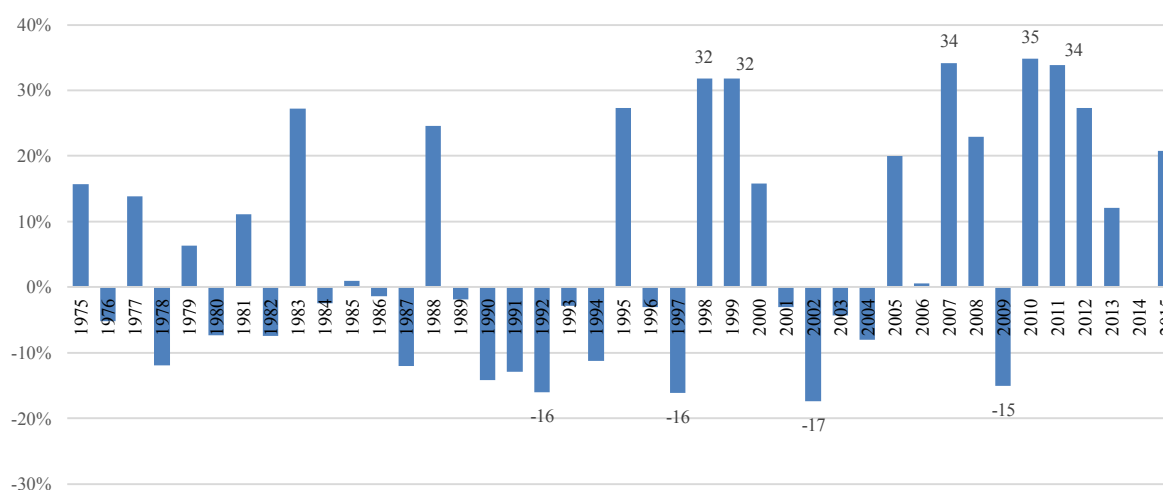
Figure 5. Observed and simulated % yield anomaly, 2005–2016

Note. $r^2 = 0.68$, $p < 0.05$

Source of basic data. PSA (2018)

Table 3. Monthly rainfall records of the PAGASA, 1975–2016, by rainfall intensity class

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1975						101%	122%	105%	60%	94%	41%	149%
1976	88%	118%	123%	131%	262%	72%	64%	116%	134%	71%	99%	124%
1977	35%	108%	21%	9%	29%	94%	173%	106%	119%	64%	76%	1%
1978	323%	65%	6%	164%	49%	71%	36%	101%	80%	127%	68%	60%
1979	23%	49%	37%	109%	90%	109%	160%	108%	80%	135%	26%	51%
1980	119%	37%	329%	16%	20%	195%	74%	91%	100%	74%	128%	62%
1981	90%	16%	29%	130%	98%	74%	28%	99%	90%	133%	78%	53%
1982	44%	55%	238%	85%	108%	166%	107%	110%	57%	67%	42%	60%
1983	102%	2%	0%	0%	41%	45%	95%	52%	76%	66%	127%	114%
1984	330%	201%	105%	223%	118%	157%	55%	111%	117%	82%	101%	70%
1985	122%	47%	42%	184%	116%	56%	62%	57%	105%	117%	73%	68%
1986	243%	8%	18%	60%	67%	102%	90%	114%	92%	104%	106%	128%
1987		57%	4%	21%	116%		133%	78%	208%	47%	77%	44%
1988	30%	9%	27%	86%	65%	79%	49%	41%	87%	236%	316%	40%
1989	180%	154%	229%	55%	128%	143%	75%	76%	49%	46%	40%	66%
1990	150%	3%	16%	6%	85%	88%	74%	124%	65%	66%	295%	17%
1991	28%	81%	76%	91%	44%	91%	89%	136%	59%	126%	199%	45%
1992	14%	3%	10%	25%	59%	152%	95%	68%	88%	97%	82%	16%
1993	8%	111%	26%	38%	31%	55%	86%	128%	45%	120%	72%	271%
1994	86%	18%	20%	455%	160%	121%	122%	98%	68%	41%	14%	94%
1995	26%	63%	128%	9%	70%	60%	100%	91%	158%	140%	104%	109%
1996	263%	229%	65%	116%	82%	61%	98%	35%	156%	122%	163%	52%
1997	44%	170%	15%	82%	94%	60%	100%		62%	45%	67%	10%
1998	1%	0%	0%	0%	101%	107%	69%	49%	98%	103%	153%	133%
1999	168%	145%	383%	312%	96%	119%	110%	93%	85%	100%	111%	146%
2000	25%	595%	269%	132%	115%	117%	96%	138%	73%	151%	187%	323%
2001	92%	117%	176%	36%	118%	119%	82%	163%	20%	142%	219%	188%
2002	16%	46%	135%	36%	82%	74%	150%	146%	90%	80%	28%	27%
2003	33%	24%	42%	35%	167%	44%	141%	76%	106%	146%		
2004	22%	49%	80%	58%	87%	127%	81%	202%	81%	125%	117%	62%
2005	11%	15%	22%	55%	129%	96%	104%	82%	93%	75%	39%	108%
2006	104%	105%	184%	12%	158%	129%	109%	170%	73%	88%	82%	199%
2007	93%	15%	33%	48%	59%	86%	124%	90%	216%	98%	105%	67%
2008	175%	491%	340%	168%	166%	138%	114%	53%	131%	98%	47%	150%
2009			0%	282%	121%	95%	312%	70%	155%	107%	54%	
2010	39%	0%	8%	15%	53%	78%	103%	78%	141%	153%	153%	144%
2011	287%	188%	206%	213%	156%	103%	83%	104%	129%	92%	84%	204%
2012	46%	202%	324%	113%	132%	112%	136%	57%	81%	66%	65%	99%
2013	34%	146%	161%	116%	146%	128%	93%	99%	161%	59%	0%	139%
2014	260%	14%	64%	135%	113%	63%	125%	91%	91%	90%	116%	244%
2015	48%	18%	4%	107%	73%	114%	0%	157%	142%	57%	26%	23%
2016	99%	226%	102%	132%	97%	102%	83%	139%	77%	147%	123%	133%

**Figure 6.** Simulated % yield anomaly, by planting year, 1975–2015, Negros Occidental

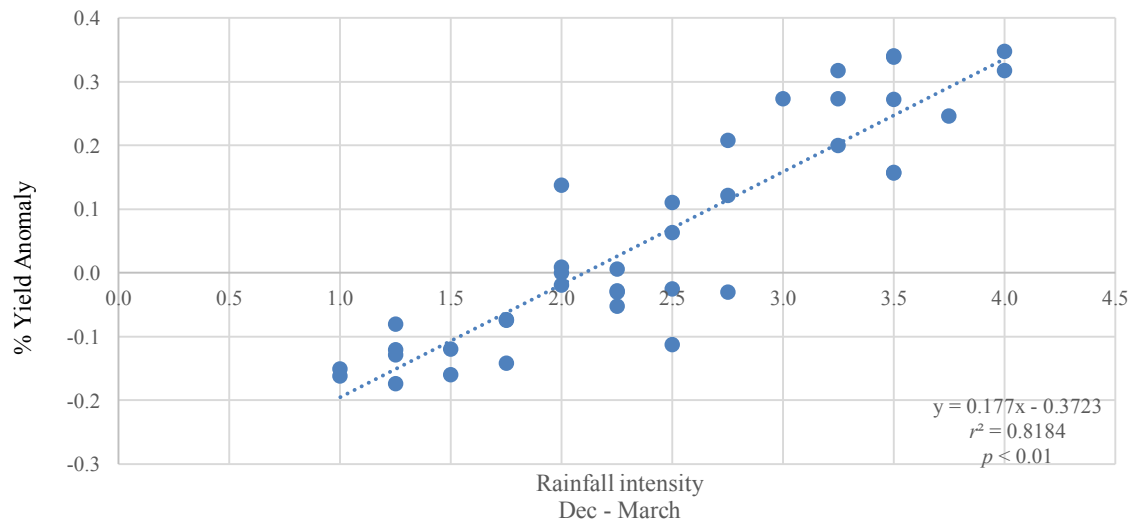


Figure 7. Correlation of dry months' rainfall to annual yield, 1975–2016, Negros Occidental

Note. $r^2 = 0.81$, $p < 0.01$

Below normal or *way below normal* rains during these months, such as those during the El Niño years, reduced average yield by 15%. On the other hand, above average rains, such as those during La Niña, increased yield by 20%. The high r^2 score shows that the December to March composite rainfall index is a good predictor of annual yield anomaly. This also indicates the positive effects of irrigation applied during these dry months.

Shifting Planting Dates

This section examines how shifting the planting month would affect yield. The model assumes that soil moisture is at field capacity, which means that initial irrigation is accessible even in the dry months. Figure 8 shows the box plots of yield by planting month from 1975 to 2016. The results show that the optimal planting months were from February to May when yield ranges from 60–70 t/ha.

Figure 8 shows that the planting season of February to May have higher yields due to the ability of the crop to draw on excess rainfall, and this is accordingly used to supply crop transpiration demand during the vegetative stage and throughout the course of the yield-forming months. At the onset of the dry period in the early part of the year, plants begin to mature and their water requirements begin to drop. Water stress at this time can benefit the crop as it induces the plant to increase sucrose content before harvest (Zhao & Li, 2015).

Most of the crop's water requirements are supplied by rainfall; thus, the net irrigation requirement was lower during these planting months (March to May). Beyond June, late planting reduces yield to 40 t/ha and below. This is due to water stress during the summer months (February to April) when the plant is in the middle of the growing season. The plant's net irrigation requirement consequently rises at this time.

Net Irrigation Requirements

Irrigation plays an important role during dry spell events. Figure 9 shows the estimated monthly average net irrigation requirement from 1975 to 2016, which ranges from 150 mm to 350 mm. With irrigation, crop transpiration increased by 97% or from 531 mm to 1,044 mm during the period 1975–2016. About 30% (288 mm) of the water transpired by the plants came from irrigation, whereas 70% were supplied by rainfall (not shown).

Figure 10 presents the simulated interannual net irrigation requirement from 1975 to 2015. The data show that the planting years with high net water requirements (up to 500 mm) are 1991, 1992, 1997, 2002, and 2009. Each of these years coincides with El Niño episodes that happened in the year succeeding them. During a major dry spell, irrigation can supply up to 50% (or 500 mm) of the plant water requirements. The least water requirements (less than 100 mm) were simulated during the La Niña years (e.g., 1998, 1999, 2007, 2010, and 2011) (not shown).

The IWUE measures the yield returns from irrigation. The higher the IWUE, the higher the returns from irrigation would be. The results show that IWUE ranges from a low 1.5 t/ha to a high 24 t/ha per 100 mm of water applied, depending on the planting month (Figure 11). IWUE rises starting March and then peaks in January.

IWUE increases during those planting months when the growth cycles mostly depend on summer irrigation for plant survival. For example, January planting will require more irrigation and is therefore less efficient than the March planting.

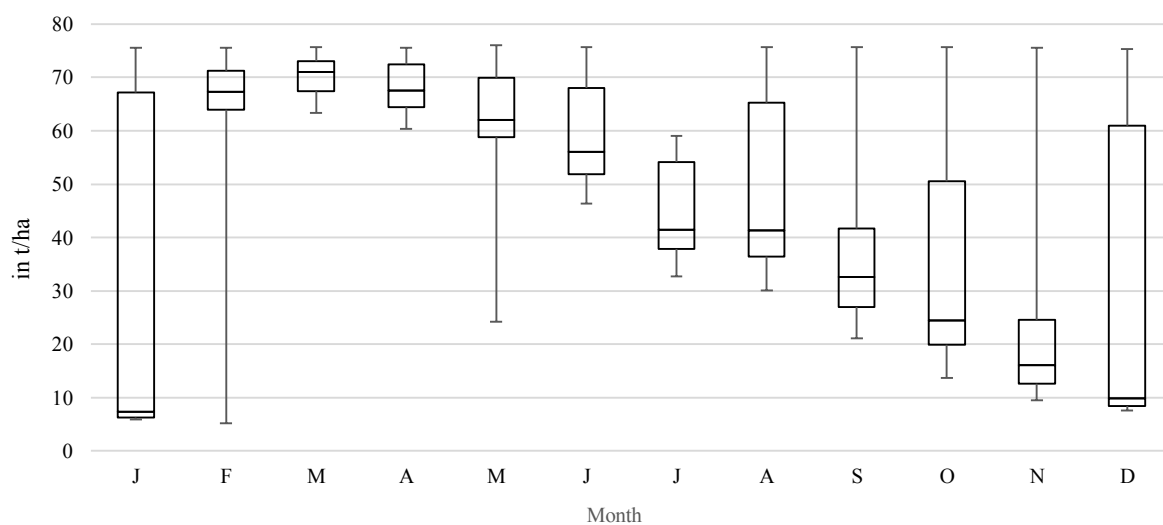


Figure 8. Yield box plot, by planting month, 1975–2016

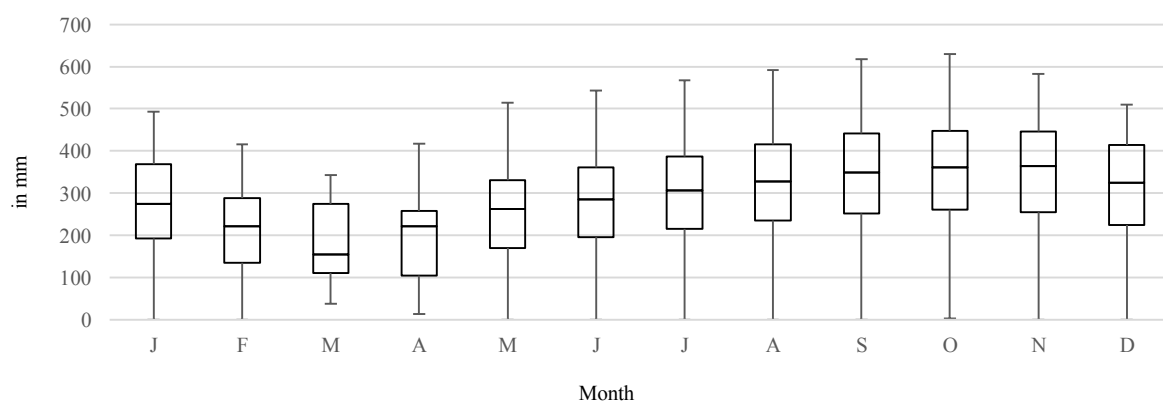


Figure 9. Estimated annual net irrigation requirements, by planting year, 1975–2016, May planting

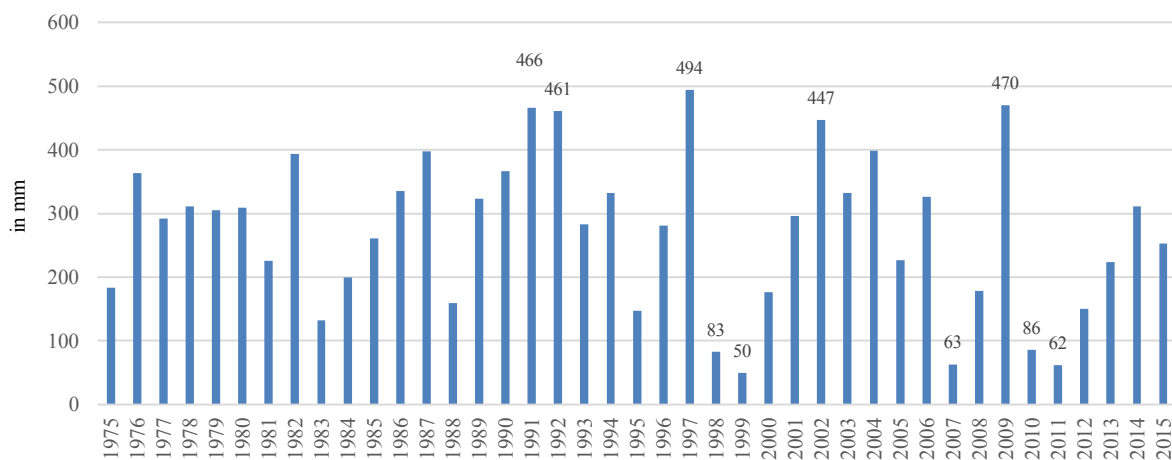


Figure 10. Simulated annual net irrigation requirement, by planting month, 1975–2016

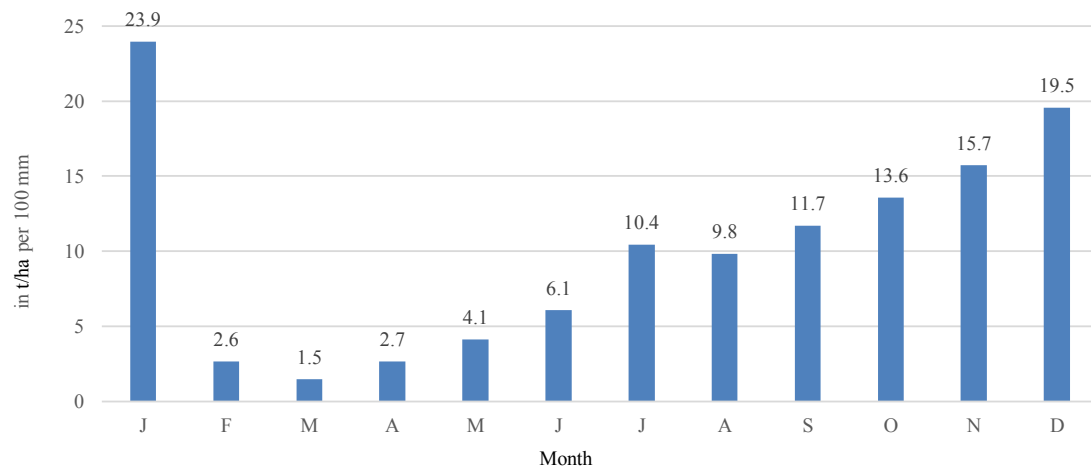


Figure 11. Simulated irrigation water use efficiency, by planting month, 1975–2016

Future Production

Table 3 summarizes the results of the crop yield simulations for the baseline and 2050 projection periods of both *with and without CO₂ effects*. Planting during the dry months implies access to supplemental irrigation.

In summary,

- Yield would increase during wetter summer months by 2050 for all planting months, with values ranging from 5% to 30%. Yield would increase in March, April, May, June, and July planting dates at $p < 0.05$ (not shown).
- Yields from May and March planting are expected to increase by 9% and 8%, respectively, by 2050.
- Temperature effects would reduce the length of the growing season by 10% (36 days). *With no CO₂ effects*, the reduction would be almost the same (11%).
- CO₂ fertilization would increase WPET by 7%. Without CO₂ effects, WPET would decrease by 3%.
- Transpiration would decrease by 3% by 2050 as WPET increases. The effect of *No CO₂ scenario* on transpiration by 2050 is insignificant (–1%).
- Net irrigation requirement under climate change would decrease by 8% (assuming May planting), albeit it would be negligible (–1%) under the *No CO₂ scenario*.
- Year-round irrigation would increase yields of rainfed farms by 17% or from 62.9 t/ha to 73.8 t/ha (assuming May planting).

Wetter summers explain the increased yields of rainfed farms under climate change. The elevated CO₂ effects on photosynthesis and transpiration show a 7% improvement in the overall WPET. Net irrigation requirements under climate change would decrease by 8%, assuming a May planting month, with 4% average reduction for all months.

Cane yields would increase under climate change due to the expected increase in the interception of radiation. This interception of radiation, in turn, results from the accelerated canopy development due to higher temperatures, wetter summers, and higher CO₂ fertilization effects on photosynthesis. As canopies develop faster, the soil loses less moisture from evaporation; thus, the plant absorbs more moisture (Allen, Pereira, Raes, & Smith, 1998).

The *No CO₂ scenario* show small (from –1% to –2%) decreases in biomass despite large decreases (–11% or 38 days) in the growth cycle. These reductions are due to the higher temperatures, albeit the reduction is not high enough to affect biomass during the yield-forming months. Water productivity shows an opposite effect, diminishing from 7% to 3%.

Shifting the planting dates from May to March would increase yield by 13%. CO₂ fertilization effects would add 8% or an overall 21% improvement. This assumes that farmers can access irrigation when the planting month shifts to March. Full irrigation for March planters is not recommended due to marginal benefits, as indicated by the low IWUE.

Table 4. Summary results of crop yield simulations under climate change with and without CO₂ fertilization effect

Output	Baseline (388 ppm)	Future 2050 (468 ppm)	% Change	No CO ₂ Effects 2050 (388 ppm)	% Change
Average annual Tmax, °C	31.74	32.50	2*		
Average annual Tmin, °C	23.80	24.60	3*		
Average annual rainfall, mm	2,642.30	2,563.00	-3		
Average annual ETo, mm	1,531.00	1,561.60	2		
Fresh stalk mass, t/ha (rainfed, May planting)	62.90	68.80	9*	62.90	0
Fresh stalk mass, t/ha (rainfed, March planting)	71.00	76.30	8*	69.40	-2
Fresh stalk mass, t/ha (irrigated, May planting)	73.80	79.50	8	72.90	-1
Growing cycle, days	360.00	324.00	-10	322.00	-11
Net irrigation requirement, mm (May planting)	263.00	243.00	-8	260.00	-1
Net irrigation requirement, mm (all months)	288.00	277.00	-4	291.00	1
Transpiration, mm (irrigated, May planting)	1,020.00	992.00	-3	1,029.00	1
WPET, kg/m ³	2.20	2.34	7	2.11	-3

Notes: * refers to values that are significant at $p = 0.05$. ETo = evapotranspiration. Tmin = minimum temperature. Tmax = maximum temperature. WPET = water productivity

Conclusions

Changes in climatic conditions have and will continue to directly or indirectly affect sugarcane production. The most significant challenges to sugarcane production are the more frequent and intense occurrence of extreme weather events, especially during ENSO events. The 40-year-old rainfall records presented in this study have captured past weather extremes, thereby improving the understanding of the impacts of ENSO and extreme events on cane yield.

The trends in cane productivity predicted in this study under elevated temperatures and CO₂ levels are consistent with the earlier studies reviewed in this article. This study found that cane yield would increase by 5%–30% by 2050, which is consistent with the 4%–29% yield increase reported in the past studies. The 8% yield increase for rainfed farms are higher than the 5%–6% yield increase reported by Sexton, Everingham, Berber, and Stokes (2014) in Australia.

The results are also close to the 10% increase reported by Marin et al. (2013) in Brazil, which has similar climatic conditions as the rainfed farms in the Philippines, where rainfall is also high (Stokes 2016). The predicted improvements, however, may be overstated because the effects of the changed climate on other factors, such as pests and diseases, were not considered in this study. The mid-century climate projections that were generated differ from the PAGASA forecasts. The projected temperature increases of 0.75 °C in this study are lower than that of the PAGASA. Its effect on yield would not be high enough to reduce cane yields substantially. The median change in rainfall shows wetter summers, and this value also differs from the PAGASA forecast. Projecting rainfall during the months of December to March is particularly critical as it affects 68% of yield variability.

Many of the models simulated in this study do not agree on the rainfall projections, which indicate that rainfall is difficult to model. This study recommends using multi-scenario probabilistic models and expanding ensemble simulations such that other GCMs and regional climate models can be included. This approach can overcome the limitations posed by the single GCMs that the PAGASA uses in projecting future climate scenarios. Deploying crop models for large spatial scales has been constrained by data collection, which can be costly and time consuming. This study has demonstrated, even without rigorous primary field data, that minimum data requirements can also be used to extrapolate modeling results from field to provincial scale, provided that the minimum conditions are met. This approach is recommended for crops grown in provincial landscapes with relatively homogeneous topography such as flood plains, valleys, and lowlands, which account for majority of production.

A protocol for regional assessments, adapted from the recommendations of van Wart (2013), can include the following:

1. Select and rank the most productive provinces for the crop under study. Start with homogeneous landscapes found in the major islands of Luzon, Mindanao, and the larger islands comprising the Visayas region.
2. Within the highest-ranked province, select the reference weather station. Check historical weather data for length and quality. Sum the crop area within a 100-kilometer-radius buffer zone from the reference weather station. Check if 40% of harvest area is covered. If 40% is not reached, then add the next ranking reference weather stations that do not overlap with those buffer areas already included. Repeat the procedure until 40% of the harvested area is covered.
3. Specify current average sowing date, maturity date, plant density, and dominant soil type for the homogeneous landscape. These should be representative of what farmers use in the target location and cropping system.
4. Apply the weighing procedure for yield estimates based on the area of rainfed vis-a-vis irrigated farms.
5. Choose the appropriate crop model that has been validated for the crop under study.

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Impacts of Carbon Dioxide Emissions on Global Intense Hydrometeorological Disasters

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Abstract

This research explains the factors that contribute to the global increase in the frequency of intense hydrometeorological disasters, particularly those related to floods and storms. It describes how the atmospheric carbon dioxide (CO₂) accumulation and its associated changes in climatic patterns contribute to the increased frequency of these intense events. The novelty of this study lies in how climate effects are examined within a socioeconomic framework that includes factors that turn natural hazards into intense disasters. These factors include people's increasing exposure and their vulnerability to these hazards.

This study uses climate data from 155 countries, with a period spanning 46 years (1970–2016). It adopts a statistical and econometric approach, instead of climate models, to assess the factors that have contributed to the increase in the frequency of intense flood and storm events. The findings show that in addition to socioeconomic factors, the continuous increase in atmospheric CO₂ concentration during the past four decades is significantly correlated with the increase in the number of extreme flood and storm events. Moreover, the results show that global climate conditions significantly affect the frequency of these disasters.

The estimates in this study further suggest that if current trends in environmental degradation and CO₂ accumulation remain unchecked, then the frequency of intense hydrometeorological disasters would increase. Our results also highlight the link between climate change and natural hazards, and support the broader pathways between climate hazards and socioeconomic variables traced by Mora et al. (2018). This scenario is a ground for the immediate implementation of adaptation measures and for taking strong mitigation measures to reverse runaway climate change.

Keywords: climate change, weather, carbon emissions, exposure, vulnerability, disaster risk

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Introduction

The frequency of natural hazard incidents across geographical regions and the steady rise in the number of economic disruptions resulting from these incidents have tripled in the past 40 years (Guha-Sapir, Hoyois, & Below, 2015). Although the trend in the number of geophysical events (e.g., earthquakes and volcanic eruptions) have remained relatively flat over the years, those of hydrometeorological (e.g., floods and related landslides, storms, and heatwaves) and climatological events (e.g., droughts and wildfires) have shown an uptick (Thomas 2017; Emanuel, 2005; Webster, Holland, Curry, & Chang, 2005). The crucial issue is whether climate change is related to this significant increase in the frequency of intense hydrometeorological and climatological disasters.

Our interest lies in the relationship between the climate phenomenon and human action. The body of published evidence indicates that the temperature of the Earth's atmosphere and oceans have been increasing, there is loss of sea ice and melting of ice sheet in the Arctic, and sea levels are rising (Levitus, Antonov, Boyer, & Stephens, 2000; Levitus et al., 2001). Moreover, over the past 60 years, greenhouse gas (GHG) emissions (i.e., carbon dioxide [CO₂], methane [CH₄], ozone, and nitrous oxide) have been increasing, mainly due to the contributions of economic-driven anthropogenic activities that have led to rising temperatures (Intergovernmental Panel on Climate Change [IPCC], 2013, 2014; Mora et al., 2018; Cheng et al., 2017).

Previous studies on the relationship of climate change and disasters have mainly focused on specific geographical regions (Stott, Stone, & Allen, 2004; Otto, Massey, van Oldenborgh, Jones, & Allen, 2012; Hoerling et al., 2012; Rahmstorf & Coumou, 2011) and particular events (Min, Zhang, Zweirs, & Hegerl, 2011; Stott et al., 2013; Nuccitelli, 2014; Kundzewicz et al., 2014; Arnell & Gosling, 2016; Hirabayashi et al., 2013; Herring, Hoerling, Peterson, & Stott, 2014). Some have applied climate change models to selected episodes (Lee & Lee, 2016; Diffenbaugh, Swain, & Touma, 2015). These climate change models have analyzed extreme climatic events in particular settings (Easterling et al., 2000; Pall et al., 2011; Schreider, Smith, & Jakeman, 2000).

In Mora et al. (2018), the authors have developed a global index of projected changes in hazards to predict the impacts of climate hazards on the population. Accordingly, they have found that floods and storms have affected the economy, infrastructure, health, and food and water security. The biggest impacts are expected to happen in South America, Southeast Asia, and northern Russia due to flooding and storms. Mora et al. (2018) have concluded that climate-related damages will greatly increase if GHG concentrations continue to rise throughout the 21st century.

Our research provides fresh evidence that connects climate change and hydrometeorological calamities based on econometric evidence that links atmospheric CO₂ accumulations to floods and storms. The present study considers all (reported) significant hydrometeorological disasters in 155 countries over the last 46 years. Furthermore, we include worldwide disasters, instead of selecting only a few cases as is usually done. In this way, we reduce the risk of selection biases (Heckman, Ichimura, Smith, & Todd, 1998). Also, hydrometeorological disasters have been more difficult than climatological ones to relate to climate change using climate models. As such, applying econometric techniques to these hydrometeorological disaster data and to their hypothesized contributing factors can help to solve this issue (Cornwall, 2016; Hsiang, 2016).

Climate models are constructs of physical relationships that can be used to predict future outcomes. This paper uses a different, but complementary, approach to examine the data on experiences (see also Pretis, 2019). Specifically, our study applies an econometric approach to determine behavioral relationships between disasters and their contributors in order to guide policy makers in formulating climate-related policies. Moreover, the method relies on the recorded natural hazards data of the Centre for Research on the Epidemiology of Disasters (CRED) to determine whether global climate factors—in addition to the effects of country conditions (e.g., local temperature and precipitation)—can explain the upward trend in the frequency of intense hydrometeorological disasters.

Aside from changes in local temperature and precipitation, global and regional climatic factors can increase the exposure and vulnerability of several countries against hydrometeorological and climatological disasters. Sea level rise due to climate change could exacerbate the destructive impact of increased local precipitation, whereas storm surges can be aggravated by sea level rise that results from the larger volume occupied by warmed water molecules and melting land ice (Mora et al., 2018). Nevertheless, these impacts would show considerable national and local differences.

Establishing causality beyond association is difficult due to the complex interrelationships among natural, geographic, and economic factors (see, Banholzer, Kossin, & Donner, 2014; Shaw et al., 2016). Thus, we rely on a cointegration analysis to determine whether there is a meaningful connection between the incidence of hydrometeorological disasters and the concentration of CO₂ emissions. If there is, then the following question remains: *what is their likely direction of causality?* Econometrically, having considered a country's conditions (e.g., exposure to the hazard, people's vulnerability, precipitation anomalies, and fixed effects per country), atmospheric CO₂ accumulation has a positive effect on the frequency of intense disasters due to floods and storms.

Finally, this paper places environmental and climate impacts within a framework that integrate geographic, economic, social, and institutional considerations into the research. Many studies have dealt with either the socioeconomic side or the climatic side only. This is mainly because disaster models stress the role of people's exposure to the calamities and their vulnerability or lack of resilience in facing them (Tyler & Moench, 2012; Banholzer et al., 2014; Hauer, Evans, & Mishra, 2016; Hallegatte & Rozenberg, 2017).

Country experiences tell us that risks result from the interplay among three elements. One of them is a highly intuitive factor, which is people's *risk exposure* due to their location or positioning of habitats, livelihoods, assets, and resources. The second factor is *vulnerability*, which is reflected on people's inability or lack of capacity to adjust and withstand hazards. The third consideration is the *nature of the hazard* itself, both in terms of its intensity and frequency of occurrence. The interplay of these three factors induces the transformation of a hazard into a disaster.

Accordingly, disaster risk can be understood as a product of the probability that the hazard would occur and of the impact that this hazard would have. By including these factors, we can see the additional contribution of climate factors (if any), and open the discussion for the interaction among all three variables. The implication is that planners need to use a multipronged approach that draws on different (but related) disciplines such

that adaptation responses will be effective against the increasing risk of these disasters.

Studies have predicted that if atmospheric CO₂ concentrations doubles, the frequency of Category 5 storms would triple (Anderson & Bausch, 2006). Moreover, Grinsted, Moore, and Jevrejeva (2013) cited that for every 1 °C rise in global temperature, the frequency of events like hurricane Katrina could increase by at least two times, and possibly by as much as seven times.

Climate models have also projected a 3%–5% increase in wind speed per degree Celsius increase in tropical sea surface temperatures (World Meteorological Organization, 2006), whereas some have indicated that the intensity of tropical cyclones would increase by 2%–11% by 2100 (Knutson et al., 2010). With climate change, global economic losses from hurricanes could double (Hallegatte, 2012). Recent projections have also raised new concerns on global warming. The continuous rise in GHG emissions has significantly increased the vulnerability of humanity to climate hazards (Mora et al., 2018).

This paper is complementary to these efforts, but goes further such that it determines the local and global climate impacts within a socioeconomic model of disasters (Figure 1).

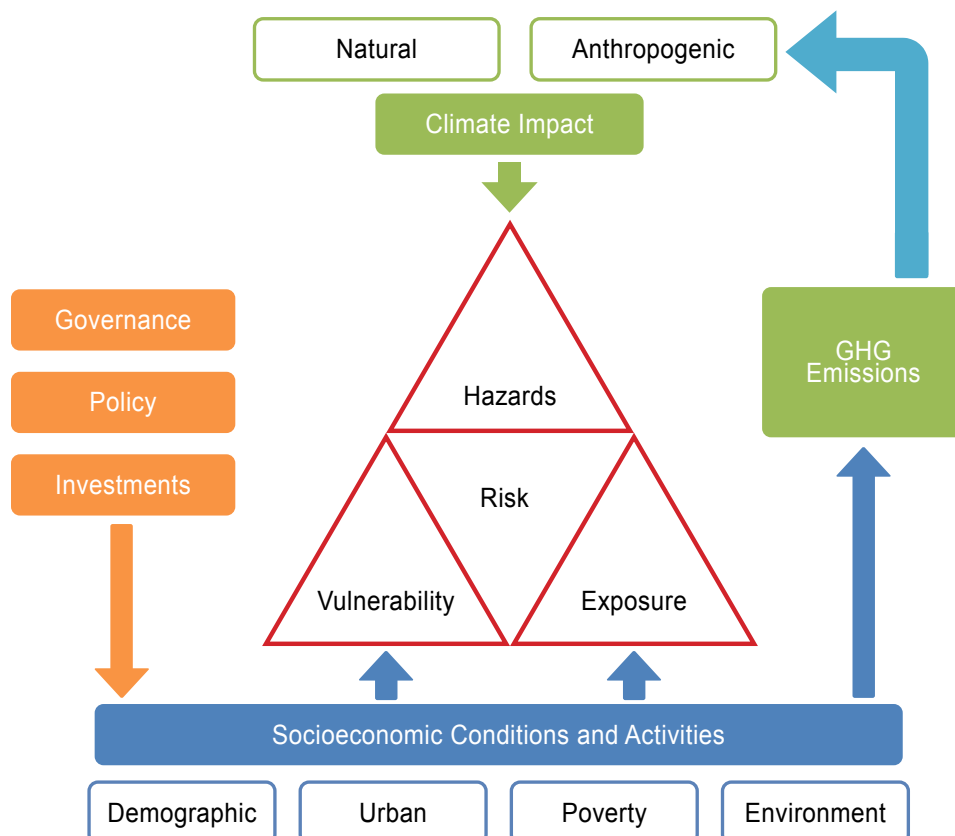


Figure 1. A framework for the disaster-climate relation

The Approach

Our approach builds on previous analyses on the climate-disaster link in order to analyze a large, global database of cross-sectional and time series data, and consequently investigate the key relationships among variables. We apply econometric and statistical methods to ensure robust findings. Note that global climate considerations that are beyond country effects¹ should be considered. Accordingly, the econometrics touches on attribution beyond contribution, without claiming too much in terms of causality. The framework we use is straightforward in establishing that the rise in the frequency of disasters depends on multiple factors, and the effects of this increase can be tested empirically.

This research provides the rationale for using the frequency of hydrometeorological disasters as the dependent variable. In this study, this variable is represented by the number of intense disasters² (per country). An intense hydrometeorological disaster is a subsample of all hydrometeorological hazards.

Also, there are other measures of disasters, such as damages in monetary terms. However, measuring natural disasters in financial terms raises data issues regarding its accuracy since standards for estimation vary across economies. Thus, the basic approach is to establish yearly data on the frequency of intense hydrometeorological disasters for as many countries, and then attempt to explain these events within a model that includes exposure and vulnerability while using climate indicators as the independent variables. In this paper, we use a full set of data from published sources for 155 countries for the period 1970–2016 using the Emergency Events Database (EM-DAT) of the CRED (see EM-DAT data in Guha-Sapir et al., 2015).

To see the likely contribution of global climate change to the frequency of intense hydrometeorological disasters beyond their country effects, one approach is to estimate the effect of global climate indicators on natural disasters. These climate indicators can be represented in the regression model by the atmospheric CO₂ concentration as a contributor, after considering the country-specific effects. This approach is called the *one-way fixed effect*; it postulates that different countries have their own distinct method of managing intense natural disasters. One problem with this approach is that the CO₂ level variable may correlate with the omitted variables

(i.e., variables that are not included because of lack of information); this may affect the disaster variable, and possibly render the estimates of the effect of CO₂ level to be biased. If these omitted variables are fixed over time, then they can be captured in the fixed effect by country; as such, the bias would not be an issue. However, if some of them vary over time, then they would be correlated with CO₂ levels or another explanatory variable, thereby generating bias in our results.

Accordingly, we employ another approach to correct this problem and then estimate the model in two stages. In stage I, we use a *two-way fixed effects* method, in which we control for both country-specific and global effects (which vary over time). These global effects are assumed to be the same among countries, albeit their size can be different through time. Global temperature, for example, is a variable that can be captured by the second fixed effect. The global effects, over and above the country effects, may include both global climatic effects and other global changes such as better technology for early warning.

In stage II, we do a cointegration analysis between atmospheric CO₂ accumulation and the estimated global time effects to test whether the latter are significantly related to CO₂ accumulation. Previous studies have established that CO₂ accumulation affects sea levels and their temperatures *inter alia* by reducing polar ice caps (Alley et al., 2003). As sea levels and their temperatures rise, the effects of local temperatures and precipitation on disasters may worsen (Griffiths et al., 2009; Huq et al., 2004). Higher precipitation may have a bigger effect on flooding if the sea level is already high (Magadza, 2000). Specifically, the dependent variable we employ is the annual frequency of intense hydrometeorological disasters (H_{it}), which is defined as floods and storms³ using data from EM-DAT (Guha-Sapir et al., 2015). On average, there were 0.7 intense hydrometeorological disasters per year among the 155 countries from 1970 to 2016 (Table 1).

One question that is often raised is: does improved disaster reporting due to the development of information and communications technology over time mean that we understand the incidence of past events? By focusing on intense hydrometeorological disasters, we consider here those events that would have been likely reported over time. Some studies consider the level of damages in US dollars based on past data; but meaningfully measuring the impact of disasters in monetary terms is constrained by the lack of standards to compare the estimates across countries.

¹ In this study, we refer to **country effects** as those climate change impacts that are specific to a country but can vary over time, such as temperature, precipitation. On the other hand, **global effects** are those that are common across countries, while varying over time such as carbon emissions in the atmosphere and global temperature.

² We define disasters in this study as those natural events that lead to a certain number of deaths (≥ 100 people) and/or people affected ($\geq 1,000$ people needing immediate assistance with food, water, shelter, sanitation, or medical assistance) in a given period of time.

³ In this study, we consider those flood and storm events as those events that cause at least 100 deaths and/or directly affect at least 1,000 people.

Table 1. Hydrometeorological disasters across countries, 1970–2016

Variable	Obs.	Mean	SD	Min.	Max.
Dependent Variable					
Frequency of intense hydro-meteorological disasters	6,109	0.723	1.660	0.000	25.000
Ln of population density (in people/km ²)	6,109	3.847	1.484	0.076	9.971
Ln of GDP, (per capita constant 2010 USD)	6,109	8.148	1.413	5.101	11.425
Square of Ln GDP (per capita constant 2010 USD)	6,109	68.255	23.452	26.021	130.526
Average precipitation deviation (in mm)	6,109	−1.836	16.654	−154.599	161.902
Population (in million)	6,109	39.197	134.527	0.040	1,378.665
Global Variables (1970–2016)					
CO ₂ level (parts per million)	47	359.550	20.606	324.933	398.123
CO ₂ deviation from level in 1970 (parts per million)	47	34.533	23.040	0.000	78.560

Source: EM DAT data, and authors' calculations.

Meanwhile, one independent or explanatory variable is the *people's exposure to hazards*, (U_{it}). This exposure pertains to the presence of people and assets in geographic locations affected by natural hazards. As a proxy for the degree to which people might locate in risky areas, we use some widely available measures of population density. Cities are naturally featured to be highly exposed as they have high population densities and asset exposures. Many cities with very high population densities (e.g., such as Bangkok, Jakarta, and Manila) are also built on flood plains or low-lying coastal areas. Among the highly exposed major cities in the world, the top seven are in Asia (Maplecroft, 2015).

A second explanatory variable is *people's vulnerability to the hazards* (V_{it}). This is influenced by socioeconomic factors and is related to the people's capacity to protect themselves. As a proxy, we use GDP per capita estimates. Looking at the data, we can see that the measure of vulnerability deteriorates as income initially increases before it improves at higher income levels (Kellenberg & Mobarak, 2008). Rising incomes in low-income countries seem to increase risky practices, disaster risks, and hence people's vulnerability. As income rises further, these risks seem to be more than compensated as the countries are able to afford infrastructure and institutions to ameliorate the risks.

The role of income in representing vulnerability is intuitive. Majority of the deaths from disasters have occurred in lower-income countries, whereas within countries, the poor are hit the hardest (IPCC, 2012; Mora et al., 2018). That said, natural hazards have been increasingly affecting both developed and developing

countries. Likewise, lower incomes are associated with weak government capacity and lack of basic facilities that would have enabled them to be resilient to disasters. A country with a GDP per capita of USD 12,800 would significantly suffer from fewer deaths than another country with a GDP per capita of USD 3,200 from a similar disaster (Kahn, 2005).

In this paper, we include a third variable—namely, a *climate variable*—within the socioeconomic model of disasters. That is, we look at the contribution of climate-related variables to the increase in the frequency of hydrometeorological disasters, in addition to the contribution of exposure and vulnerability. As a reflection of the effect of climate change, we use publicly available data on the average precipitation deviations in the country (Schneider et al., 2011). These deviations are estimated in terms of the divergence from the average for the time period 1961–1990 (W_{it}).

A crucial independent variable in this analysis is the *global effect* (G_t). In the first approach, the variable G_t is represented by the accumulated CO₂ in the atmosphere based on in situ air measurements by the Mauna Loa Observatory (Tans & Keeling, 2015). This is then coupled with country dummies to have a variable reflecting differing country response.

In the second approach, we include time dummies per year in the regression analysis as additional dependent variables. They account for global impacts that are common-to-all-countries on the frequency of hydrometeorological disasters. Once we do the estimation, the estimated coefficients of our variable G_t

becomes the predicted coefficients of the time dummy variables. They capture global factors after controlling for exposure, vulnerability, and the climate hazard. The predicted coefficients of the time dummy variables can also capture global factors that are not necessarily related to climatic variables. For example, technological and communication improvements may increase the number of reported disasters. In the second approach, G_t can also capture the effect of more people locating in hazard-prone areas (Adger, Hughes, Folke, Carpenter, & Rockstrom, 2005; Barbier, 2015). In this case, we can artificially inflate the value of the global effects. The cointegration analysis in stage II brings out the role of CO_2 on global effects that is separate from these other non-climatic effects. Finally, v_{it} is the stochastic error, in which we assume the mean to be one. Its standard deviation σ_v is estimated inside the model (Table 2).

Since H_{it} represents the realization of a stochastic variable, we want to estimate correctly the parameters α_0 ,

α_1 , α_2 , α_3 and α_4 in Equation (1) to separate the effect of each independent variable and then determine how each affects the frequency of intense hydrometeorological disasters.

$$E[H_{it}|U_{it}, V_{it}, W_{it}, G_t, v_{it}] = \exp(\alpha_0 + \alpha_1 U_{it} + \alpha_2 V_{it} + \alpha_3 W_{it} + \alpha_4 G_t) \exp(v_{it}) \quad (1)$$

We then estimate the parameters of the following regression equation using the annual data for 155 countries during 1970–2016 (Appendix Table A1), thereby making a total of 6,109 observations. Since the dependent variable consists of nonnegative count values, count regression models such as the Poisson (P) or negative binomial (NB) need to be used. We choose the NB model because it is more general than the P model. Moreover, our preliminary statistic tests showed that the former fits the data better (see Appendix B1). Table 1 gives evidence that the model satisfies the NB assumptions because the mean and the variance (i.e., square of the standard deviation) are different.

Table 2. Determinants of intense hydrometeorological disasters using the NBZI method, 1970–2016

Explanatory Variables	Approach 1 (one-way fixed effects)	Approach 2 (two-way fixed effects) ^a
	(1)	(2)
Exposure		
Ln (population density)	1.291000*** [0.194000]	0.039600*** [0.233000]
Population (million)	0.000098 [0.000461]	0.0000345 [0.000415]
Vulnerability		
Ln GDP per capita (constant 2010 USD)	0.239000 [0.413000]	0.331000 [0.445000]
Square of Ln GDP per capita (constant 2010 USD)	−0.023000 [0.027300]	−0.035500 [0.030300]
Local Climate Condition		
Average precipitation deviation (mm)	0.001350*** [0.000124]	0.0011800*** [0.0001530]
Global climate indicator		
CO ₂ level (ppm)	0.007320*** [0.002700]	time dummy coefficients
Observations	6,190.000000	6,109.000000
Error' standard deviation (σ_v)	4.530000	3.440000
Akaike information criterion (AIC)	10,314.040000	10,156.810000
Bayesian information criterion (BIC)	11,422.430000	11,567.490000
LR Test	115.370000***	120.890000***
Vuong Test	2.50000***	2.530000***

Notes: *** pertains to estimates that are significant at 1%. Estimates in brackets are standard errors.

The dependent variable is the “count” or incidence of intense disasters. In this study, this variable is modeled for situations in which the data have an excess of zero count. As such, we find that about two-thirds of the annual country observations for intense hydrometeorological disasters have zero count. It is important to consider the presence of zeros in the dependent variable in order to avoid inconsistent estimators. Accordingly, we employ the zero-inflated (ZI) count model to avoid this issue (Johnson, Kemp, & Kotz, 2005; Lambert, 1992).

Our model also allows us to check the origin of the zero-observed dependent variable: either because a country in a year has a zero probability of having a disaster, or a country nevertheless has no disaster for random reasons despite having a positive probability of a disaster (Vuong, 1989) (see Appendix B2). By ignoring the zeroes in the dependent variable, the application of the ZI model lowers the risk of deriving inconsistent estimators. Thus, we use a combination of negative binomial and zero-inflated model (NBZI).

The estimated coefficients of the time dummies obtained from the two-way fixed effects model are subjected to a cointegration analysis (Engle & Granger, 1991) with the annual data on atmospheric CO₂. Cointegration helps us to know whether the estimated time dummy coefficients and the global climate variable are positively correlated in a non-spurious way.

However, one issue with this regression analysis is that the series may jointly trend upwards, thereby giving a positive and significant coefficient without necessarily implying that they are related (Granger & Newbold, 1974). This is the case when “the series is not covariance stationary”; this means that the series does not have finite means, and that the auto covariance changes over time. A second concern is that the relationship between the series may be influenced by the other omitted variables that are not considered in the regression.

López, Thomas, & Troncoso (2016b, p. 7) show how cointegration allows us to deal with these two problems by “testing whether particular transformations of the series yield covariance stationary processes, and hence can be used to obtain meaningful estimates, and whether omitted variables are still consistent with non-spurious correlations over the long run”. The covariance stationarity of the series of first differences does not mean that the first differences of the series must correlate. In fact, correlation between first differences exists if the series are only contemporaneously correlated. However, if the series correlates through lag effects, as is in fact the most likely case, then simply analyzing the series of first differences would not capture the lag correlation. Thus, cointegration testing allows both contemporaneous correlations and lagged effects.

If we pass the tests of cointegration, then we can assert that regardless of the omitted variables, the estimated

co-integrating coefficient may be biased (Lütkepohl, 1982) and consistent (Pashourtidou, 2003). Even here, the short-term coefficients may be biased. However, we are concerned with the long-term connection between atmospheric CO₂ concentration and the rise in the incidence of intense hydrometeorological disasters.

Note that significant correlations signaled by cointegration do not necessarily signify causality. However, we can view this as: if two variables show a non-spurious and meaningful correlation, then there must be causality in at least one direction (Granger, 1988; Asteriou & Hall, 2011). Moreover, previous knowledge may allow us to reject one of the two directions. Thus, we could have a causal relation to underlie a non-spurious correlation between the two series. Also, there are alternative causality tests that can be used to determine causality (Govindaraju & Tang, 2013).

Results

The data assembled in this study present an intuitive depiction of a rising incidence of intense hydrometeorological disasters within the socioeconomic settings of different geographical regions. The means presented give a one-shot picture, whereas the standard deviations bring out the wide variations geographically (Table 1). We focus on the incidence of what may be characterized as intense floods and storms, which vary greatly across countries and regions. Climate impacts and people’s exposure and vulnerability to climate hazards vary greatly among countries. However, what is common is the global effect of atmospheric CO₂ concentrations, which this study seeks to delineate.

The estimates in Table 2 present the core results of this study to explain the factors that determine the frequency of intense hydro meteorological disasters. The first column shows the estimate resulting from the first approach (one-way fixed effects), which uses country dummies and with the annual level of CO₂ proxying global climate change as an independent variable. The second column presents the estimates resulting from the second approach (two-way fixed effects), which uses time dummies and country fixed effects.

The estimates are intuitive and plausible. The local climate variable is highly significant and has the expected signs. Precipitation deviations exert a positive impact on the number of intense local hydrometeorological disasters. Moreover, according to one-way fixed effects, the variable atmospheric CO₂ concentration is positive and highly significant. However, this global climate variable could be correlated with other global variables, which can affect the frequency of disasters. This would imply that the CO₂ coefficient is biased.

In the two-way fixed effects model (stage I of the second approach), on the other hand, the coefficients of the time

dummy variables capture any global effects whether they are climate-related or not. The most important result is that around 70% of the estimated time dummy coefficients are significant at 10% significance level, and they also increase over time (Table 3 and Figure 2). Thus, beyond country effects, there are global effects that affect the frequency of intense disasters.

In stage II, we implement a cointegration analysis between the time dummy coefficients and the annual concentration of CO₂. The standard deviations of the errors are 4.5 and 3.40 in the first and second approaches, respectively. These values imply that although all the explanatory variables play a crucial role, there is still room for random behavior among countries. These results confirm that the population's increasing risk exposure and vulnerability to natural hazards play a role in determining the frequency of big hydrometeorological calamities. Furthermore, it shows how climate change factors help to explain the phenomenon.

Local precipitation deviations significantly affect intense hydrometeorological disasters. The parameters are positive and significant in both models, which confirm the importance of precipitation deviations as sources of intense hydrometeorological disasters. This variable has also been analyzed in the study of Thomas, Albert, and Hepburn (2014).

When we use the first approach, the global climate factor (as represented by the atmospheric CO₂ accumulation data of the Mauna Loa Observatory) appears to be very important in explaining disasters (Table 2). In the second approach, the coefficients of the time dummy variables, which may be related to CO₂ accumulation, also help to determine country disasters.

The estimates of the time dummy coefficients common to all countries in the second approach are increasing over time. They are significant when taken altogether; for the most part, each coefficient is also significant. This suggests that global factors, which are likely related to carbon emissions, impact climate disasters in addition to the influence of local factors. This finding makes a strong case for global action in addition to what is currently being done at the country and local levels.

Role of Global Warming

Several papers have argued that a global warming similar to the current trends had already occurred in the distant past, and that the current changes in climatic patterns cannot be solely attributed to human activities (see for example, Michaels, 2008). Most of the scientific evidence summarized in the 2014 IPCC report presents more broadly the link between the more recent global warming and the accumulation of CO₂ and CH₄ in the

Table 3. Estimated Coefficients of the Time Dummy Variables (Approach 2 Stage I)

Year	Coef.	Year	Coef.	Year	Coef.	Year	Coef.	Year	Coef.
1971	-0.507*	1981	0.332	1991	0.442*	2001	1.314***	2011	1.299***
	[0.288]		[0.265]		[0.260]		[0.265]		[0.302]
1972	-0.407	1982	0.482*	1992	0.709***	2002	1.357***	2012	1.375***
	[0.317]		[0.251]		[0.253]		[0.264]		[0.305]
1973	-0.307	1983	0.435*	1993	1.100***	2003	1.175***	2013	1.007***
	[0.302]		[0.236]		[0.240]		[0.271]		[0.309]
1974	-0.136	1984	0.297	1994	0.934***	2004	1.352***	2014	0.887***
	[0.296]		[0.246]		[0.259]		[0.275]		[0.325]
1975	-0.892**	1985	0.559**	1995	1.085***	2005	1.505***	2015	1.186***
	[0.347]		[0.240]		[0.249]		[0.283]		[0.319]
1976	-0.439	1986	0.483**	1996	0.886***	2006	1.554***	2016	0.924***
	[0.302]		[0.235]		[0.268]		[0.286]		[0.322]
1977	0.143	1987	0.580**	1997	0.738***	2007	1.550***		
	[0.269]		[0.237]		[0.257]		[0.285]		
1978	0.407	1988	0.653***	1998	1.059***	2008	1.436***		
	[0.261]		[0.244]		[0.270]		[0.289]		
1979	0.169	1989	0.303	1999	1.047***	2009	1.394***		
	[0.270]		[0.265]		[0.266]		[0.290]		
1980	0.212	1990	0.370	2000	1.207***	2010	1.477***		
	[0.239]		[0.246]		[0.269]		[0.296]		

Notes: * = significant at 10%, ** = significant at 5%, *** = significant at 1%. Standard errors in brackets.

atmosphere (IPCC, 2014). Figure 3 gives the basic motivation for tracking this link.

Accordingly, a time-series analysis could show whether there is indeed a significant relationship between the increased global effect and the accumulated stock of CO₂. The test is whether the series of time dummy coefficients and CO₂ accumulation would cointegrate. If they do, then there is likely a non-spurious relationship between global warming and disasters on the one side and atmospheric CO₂ accumulation on the other.

The first panel of Figure 2 shows the estimated coefficients of the time dummy variables for intense

hydrometeorological disasters and CO₂ concentrations from 1970 to 2016. Both series show rising trends during the period. The series in levels appear to be non-covariance-stationary, suggesting that any regression between the two data series that give values of the variables in levels would yield spurious estimates. Accordingly, the Dickey-Fuller test suggests that the series are indeed non-covariance-stationary (Elliott, Rothenberg, & Stock, 1996; MacKinnon, 1994).

The second panel of Figure 2 shows the series expressed in first differences, which appear to be stationary. We then test—as a necessary but not sufficient condition—for cointegration between the series. Also, although

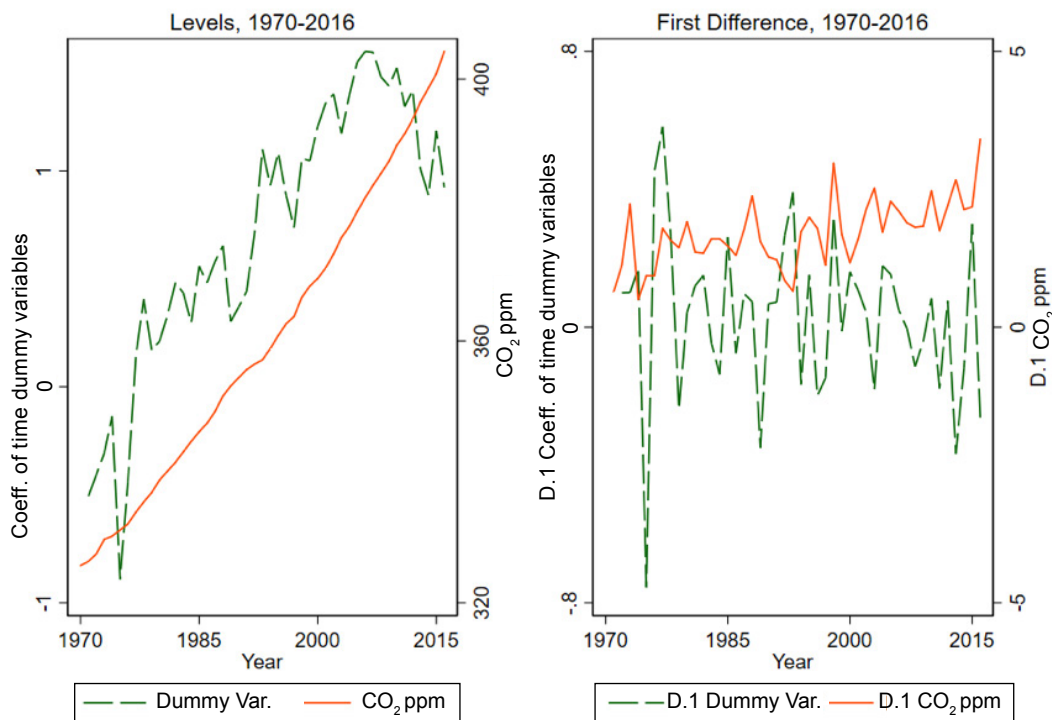


Figure 2. Coefficient of time dummy variables of hydrometeorological events and CO₂ stocks, 1970–2016

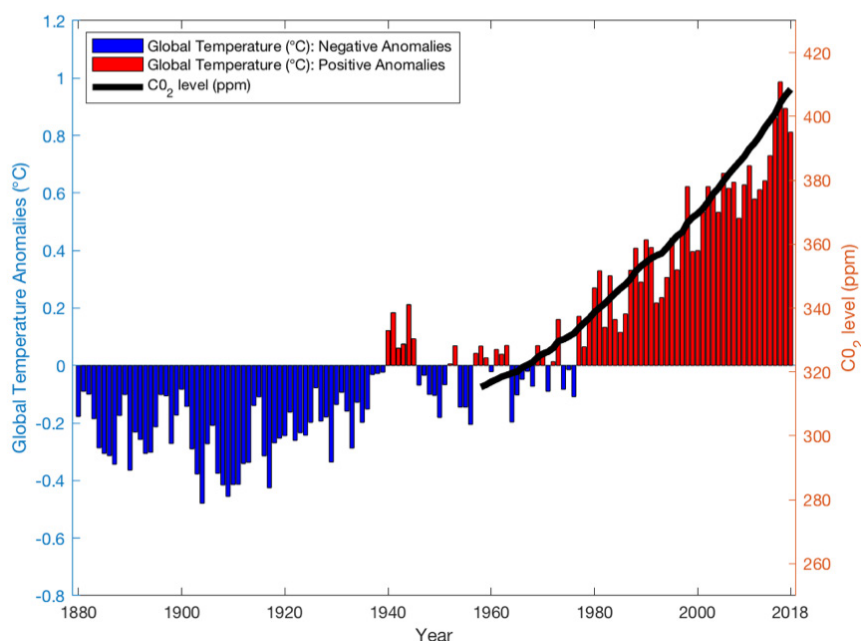


Figure 3. Global temperature anomalies (C) and CO₂ ppm
Source of basic data: NASA (2019) and NOAA (2018)

the first differences of the series may not correlate, a linear combination of the series that integrate is enough for cointegration. Thus, the lagged values of the series might correlate.

Table 4 provides this regression estimate in the first column.⁴ The standard error (not shown) is not distributed asymptotically normal, and thus the estimated coefficients can be used to test for co-integration. Even if all individual series in levels are nonstationary, the linear combination of the estimates of the two nonstationary series may be stationary. For instance, a nonstationary process with a deterministic trend becomes stationary after removing the trend (de-trending). If two series present the same “trend”, then a linear combination of both could remove the implicit trend. Indeed, it is what the cointegration process does.

Thus, given that both series in levels are not covariance stationary, if the *predicted errors* are stationary, then we have evidence of cointegration between the time

dummy values and CO₂. López, Thomas, & Troncoso (2016a, p. 7) provide details of “the tests of stationarity or cointegration using the series of predicted errors obtained from the regression estimation”.⁵ The tests allow rejecting the null hypothesis that the error is not covariance stationary, implying that the series cointegrate. We also implemented a stronger cointegration test, which estimates a vector error correction model (VECM) between intense hydrometeorological disasters and the CO₂ (Johansen, 1995). This too shows cointegration between the series (Appendix Table B1).

However, the autoregressive distributed lags (ARDL) is more advisable to use when the sample size is small (Pesaran, Shin, & Smith, 2001). Thus, we also apply ARDL as shown in the second column of Table 4. A non-spurious correlation between the series can be claimed because the coefficient of CO_{2(t-1)} is positive and significant, and the error correction coefficient ($\hat{\rho}_1$) is negative and significant.

Table 4. Regression and cointegration analysis for the disasters: CO₂

Parameter	Hydrometeorological	
	Level	First Diff. (D.1) (ECM)
CO ₂ level (in ppm)	0.0232 [0.00289]	
D.1 CO _{2(t-1)} (in ppm)		0.0228 [0.0796]
Coefficients of the Time Dummy Variables _(t-1) ($\hat{\rho}_1$)		-0.230*** [0.101]
CO _{2(t-1)} ($\hat{\rho}_2$) (in ppm)		0.00430* [0.0026]
Constant	-7.661*** [1.034]	-1.254* [0.981]
Observations	46.00000	45.000
AIC	30.63511	-0.935
BIC	34.29239	6.291
Tests for Stationarity		
Dickey-Fuller (DF)	-3.02200**	
Dickey-Fuller Generalized Least Squares (DF-GLS)	-2.59900*	

Notes: * and *** refer to values that are significant at the 10%, and 1% levels, respectively. Values in brackets are standard errors.

⁴ Method 3 in Appendix B describes the model for estimation using ordinary least squares.

⁵ See Appendix B4 for a detailed explanation of the model.

Results also show that the cointegrating coefficient is positive and statistically significant at 1% level (Appendix Table B2). Consequently, even if there are omitted variables, the estimated correlation measured by the regression analysis seems non-spurious. The estimated coefficient is then consistent (Pashourtidou, 2003) although it may be biased (Lütkepohl, 1982). Therefore, the possible existence of omitted variables does not invalidate a true relationship between the series (see one application of these tests in Shahbaz, Tang, & Shabbir, 2011).

Furthermore, if two variables exhibit a non-spurious correlation, then we can expect at least one direction of causality (Granger, 1988; Asteriou & Hall, 2011). The direction of causality, however, can be in either direction under alternative theories and computations.⁶ In the present analysis, the causal direction is likely from carbon emissions to intense hydrometeorological disasters, rather than the other way around.

Significance of the Results

Table 5 shows the estimated elasticity of the time dummy coefficients of intense hydrometeorological disasters with respect to the atmospheric CO₂ concentrations evaluated at the mean values. Elasticity is the measure of the proportional change of one variable in response to a change in another. In our case, it represents the

proportional change in the coefficients of time-dummy variables of intense hydrometeorological disasters due to a 1% change in the atmospheric CO₂ concentrations.

We now estimate the impact of the changes in the time dummy coefficients on the level of disasters by applying the measures from the two-way fixed effect regressions⁷ using the values of the second column in Table 4. The combination of these two effects gives the net effect of CO₂ on the frequency of intense disasters. Thereafter, we simulate the effects of the increases of CO₂ on the number of intense disaster by using the estimated elasticity of disasters with respect to CO₂.

Table 6 shows the elasticity of disasters with respect to CO₂ using information from 1970 to 2016. Our results show that if CO₂ level increases by 1%, then the hydrometeorological disasters would increase by 8.96 % (see Appendix B6). Using this elasticity, we then project the number of intense disasters in the future. For instance, the yearly increase in atmospheric CO₂ has been about 2.4 ppm, or about 0.6% of the base 396.54 ppm level, from 2010 to 2016. We choose this period to reflect the more recent and higher trend in the CO₂ level as compared to that between 1970 and 2016, in which the average CO₂ increase is around 1.70 ppm. Accordingly, the number of intense hydrometeorological disasters could increase by 5.4% annually for the “average”⁸ country or by 0.05 more disasters. This is with respect

Table 5. Elasticity of coefficient of time dummy variables with respect to CO₂

Parameter	Estimate
Marginal effect ($\hat{\beta}$)	0.0180
Standard deviation ($\hat{\beta}$)	0.0070
Average sample value of CO ₂ level, 1970–2016 (in ppm)	360.2134
Average value of coefficients of the time dummy variables, 1970–2016 (in number of disasters)	0.7117
Elasticity of coefficients of the time dummy variables with respect to the atmospheric CO ₂ level	9.1007

Table 6. Impacts of CO₂ emissions on the incidence of global intense hydrometeorological disasters

Parameter	Value
Elasticity of disasters with respect to CO ₂ (1970–2016)	8.96
For simulation (2010–2016)	
CO ₂ level (in ppm)	396.5
Current yearly CO ₂ increase (in ppm)	2.4
Simulated variation in intense disasters due to rate of increases in CO ₂ level (%)	5.4

⁶ See Appendix B4 for a detailed explanation of the model used in this study and Appendix Table B3 for the detailed results.

⁷ The method for deriving the estimated effects of CO₂ levels on disasters is explained in Appendix B3.

⁸ Average country stands for the simple mean across the 155 countries.

to the 2010–2016 average, which is 0.856 disasters per year. This implies that under the current trend in the increase in atmospheric CO₂ accumulation, the number of intense hydrometeorological disasters could double in 13 years or from an average of 0.856 to 1.71 disasters annually.

These estimated effects of CO₂ accumulation on disasters are not much larger than those obtained from climate change models. Likewise, climate change models predict that the increase in accumulated CO₂ stock would have massive effects on the number of intense hydrometeorological disasters. Climate model estimates predict that if CO₂ concentrations double, then the frequency of Category 5 hurricanes may triple (Anderson & Bausch, 2006). Moreover, the models estimate that an increase of 1 °C in global temperature would increase the number of Category 3 (e.g., hurricane Katrina) events by seven times (Grinsted et al., 2013). If GHG concentrations will continue to rise throughout the 21st century, then climate change—even under mitigation scenarios—will still continue to affect humanity, particularly those in the tropical coastal areas (Mora et al., 2018).

Sensitivity Analysis

Table 5 shows the cointegration coefficient (0.0180) and its standard deviation (SD = 0.007). Using the coefficient plus and minus the standard deviation, we get the interval [0.011, 0.025], which represents the most likely values for our parameter. These numbers allow us to recalculate the elasticities and the simulated variation in the frequency of intense disasters due to the rate of increase in atmospheric CO₂ level. Taking the minimum and the maximum values in the interval, we find that the number of intense hydrometeorological disasters could increase by 3.3%–7.5% annually for the “average” country. This translates to additional 0.03–0.06 intense disasters per year. Furthermore, this means that the number of intense hydrometeorological disasters could double in 10 or 21 years, depending on which extreme point in the interval we use. If we repeat the same process but use the values inside of the two standard deviations, then our cointegration coefficient moves between [0.004, 0.032]. Accordingly, we find that the number of intense hydrometeorological disasters could double between 8 and 58 years when we use both extreme numbers in the interval.

Conclusion

The frequency of intense hydrometeorological events worldwide has been increasing over the recent years. As such, governments and climate experts are scrutinizing the factors that contribute to this upward trend in order to guide policy actions. Climate experts generally agree that global warming has been observable since 1980 (Figure 3). However, there have been different views

on how much global warming contributes to the rise in intense hydrometeorological events, let alone how much of that can be attributed to anthropogenic factors.

This study has developed a framework that includes the role of socioeconomic factors (i.e., people’s exposure and vulnerability to the hazards) and has attempted to delineate the role of human-driven climatic factors in the increase in the incidence of intense hydrometeorological disasters. Specifically, we applied econometric and statistical methods to get robust results. Accordingly, our results show that atmospheric CO₂ accumulations and climate-related disasters are significantly and positively correlated. Furthermore, we find that a large proportion of the increase in the frequency of intense hydrometeorological disasters is correlated with the continuous increase in atmospheric CO₂ concentrations. Similar results have also been found in the study of Mora et al. (2018).

Reducing people’s exposure and vulnerability to climate hazards through developing and implementing appropriate climate adaptation and disaster risk reduction measures can help to lighten the increasing threats from natural hazards. The higher incidence of extreme natural hazards and even the population’s high exposure do not automatically lead to disasters. In view of this, governments should prioritize and invest in initiatives that would decrease people’s vulnerability to climate-related hazards; such initiatives could be in the form of prevention strategies and disaster risk reduction. These kinds of responses are included in our analysis either as country effects (i.e., some countries invest more than others) in approach I, or global effects (i.e., improvements among all countries, which vary over time) in approach II.

The link found in this paper between the incidence of natural calamities and increase in atmospheric CO₂ has implications for environmental and economic policies (Gaillard, 2012). Rather than reacting to events as one-off and unpredictable occurrences, human made events call for investments in prevention and mitigation programs. Our finding that the number of intense hydrometeorological disasters could double in 13 years under current trends then calls for far greater investments in disaster risk reduction and mitigation on the part of countries and the global community.

The global evidence presented in this study, together with the attribution of specific disasters to climate change in the growing literature, are grounds for far stronger economic and environmental policies to ameliorate the growing damages from natural calamities. On the one side, there needs to be climate adaptation efforts, such as relocating people from highly exposed coastal regions or building better disaster preparedness that would withstand extreme hurricanes. Equally, given the findings on the role of human-induced climate change, there is a strong case for stepping up climate change

mitigation. Countries need to invest substantially and urgently in decarbonizing their economies.

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Appendices

Appendix A. Sample Countries

Table A1. Countries considered in the analysis, 1970–2016

No.	Country	No.	Country	No.	Country	No.	Country	No.	Country
1	Afghanistan	32	Comoros	63	Hong Kong	94	Morocco	125	Slovakia
2	Albania	33	Congo	64	Hungary	95	Mozambique	126	Slovenia
3	Algeria	34	The Democratic Republic of the Congo	65	India	96	Namibia	127	Solomon Islands
4	Angola	35	Costa Rica	66	Indonesia	97	Nepal	128	South Africa
5	Antigua and Barbuda	36	Cote d'Ivoire	67	Iran	98	Netherlands	129	Spain
6	Argentina	37	Croatia	68	Iraq	99	New Zealand	130	Sri Lanka
7	Armenia	38	Cuba	69	Ireland	100	Nicaragua	131	Sudan
8	Australia	39	Czech Republic	70	Israel	101	Niger	132	Suriname
9	Austria	40	Djibouti	71	Italy	102	Nigeria	133	Swaziland
10	Azerbaijan	41	Dominica	72	Japan	103	Norway	134	Switzerland
11	Bahamas	42	Dominican Republic	73	Jordan	104	Oman	135	Syrian Arab Republic
12	Bangladesh	43	Ecuador	74	Kazakhstan	105	Pakistan	136	Tajikistan
13	Belarus	44	Egypt	75	Kenya	106	Panama	137	Tanzania
14	Belgium	45	El Salvador	76	Korea	107	Papua New Guinea	138	Thailand
15	Belize	46	Eritrea	77	Kyrgyzstan	108	Paraguay	139	Timor-Leste
16	Benin	47	Ethiopia	78	Lao PDR	109	Peru	140	Togo
17	Bhutan	48	Fiji	79	Lebanon	110	Philippines	141	Trinidad and Tobago
18	Bolivia	49	France	80	Lesotho	111	Poland	142	Tunisia
19	Bosnia and Herzegovina	50	Gabon	81	Liberia	112	Portugal	143	Turkey
20	Botswana	51	Gambia	82	Lithuania	113	Puerto Rico	144	Uganda
21	Brazil	52	Georgia	83	Macao	114	Romania	145	Ukraine
22	Bulgaria	53	Germany	84	Macedonia	115	Russian Federation	146	United Kingdom
23	Burkina Faso	54	Ghana	85	Madagascar	116	Saint Kitts and Nevis	147	United States
24	Cambodia	55	Greece	86	Malawi	117	Saint Lucia	148	Uruguay
25	Cameroon	56	Grenada	87	Malaysia	118	Saint Vincent and The Grenadines	149	Uzbekistan
26	Canada	57	Guatemala	88	Mali	119	Samoa	150	Vanuatu
27	Central African Republic	58	Guinea	89	Mauritania	120	Saudi Arabia	151	Venezuela
28	Chad	59	Guinea-Bissau	90	Mexico	121	Senegal	152	Viet Nam
29	Chile	60	Guyana	91	Moldova	122	Serbia	153	Yemen
30	China	61	Haiti	92	Mongolia	123	Seychelles	154	Zambia
31	Colombia	62	Honduras	93	Montenegro	124	Sierra Leone	155	Zimbabwe

Appendix B. Statistical Models

1. Method 1: Poisson and negative binomial distributions.

Let H be a random variable for the number of disasters. If H follows a Poisson distribution, then the probability density function is

$$\Pr(H = h | \varsigma) = \frac{\exp(-\varsigma)\varsigma^h}{h!}, h = 0, 1, \dots$$

where h is a particular value of the variable H , and H has mean and variance.

$$E(H) = \text{Var}(H) = \varsigma$$

On the other hand, if H follows a negative binomial (NB) distribution, then the probability density function is

$$\Pr(H = h | \varsigma, \pi) = \frac{\Gamma(h + \pi^{-1})}{h! \Gamma(\pi^{-1})} \left(\frac{\pi^{-1}}{\pi^{-1} + \varsigma} \right)^{\pi^{-1}} \left(\frac{\varsigma}{\pi^{-1} + \varsigma} \right)^h, h = 0, 1, \dots$$

where:

$$\begin{aligned} \Gamma(\cdot) &= \text{gamma function, } E(H) = \varsigma \text{ and variance of } V[H | \varsigma, \pi] = \varsigma(1 + \pi\varsigma) \\ &\text{and} \\ \pi &= \text{measures the degree of overdispersion (the difference between the mean and the variance of the distribution).} \end{aligned}$$

If π converges to zero, then the NB model will reduce to Poisson model. Testing for over-dispersion ($\pi = 0$) is done using the likelihood ratio test, thereby proving that the variable satisfied the NB assumptions; that is, the variance exceeds the mean (Johnson et al., 2005; Lambert, 1992).

The standard mean parameterization of NB distribution is $\varsigma = \exp(R'\alpha)\exp(v)$ [Equation (1) in the main text] where:

$$\begin{aligned} R &= \text{a vector of explanatory variables (in our case } U_{it}, V_{it}, W_{it}, G_t) \text{ and} \\ \alpha &= \text{parameters to be estimated.} \end{aligned}$$

This parameterization ensures that $\varsigma > 0$. Moreover, v is the error term with mean equal to 1 and a variance equal to π . We denote its standard deviation as σ_v .

2. Method 2: Derivation of the zero-inflated estimators.

For each country in i and year t , there are two possible data generation processes for $H_{i,t}$ —the selection of which is a result of a Bernoulli trial. The first process, which generates only zero counts, is chosen with probability ρ_i . The second process $g(H_{it} | R_{it})$ with probability $1 - \rho_i$ generates positive counts from an NB distribution where R_{it} is a vector of explanatory variables (in our case $U_{it}, V_{it}, W_{it}, G_t$).

In general, we have

$$H_{it} \sim \begin{cases} 0 & \text{with probability } \rho_i \\ g(H_{it} | R_{it}) & \text{with probability } 1 - \rho_i \end{cases} \quad (\text{B1})$$

Then the probability of $\{H_{it} = h_{it} | R_{it}\}$, where h_{it} is a particular value of the variable $H_{i,t}$, can be expressed as (Johnson et al. 2005; Lambert, 1992):

$$P(H_{it} = h_{it} | R_{it}, I_{it}) = \begin{cases} \rho(\lambda' I_{it}) + \{1 - \rho(\lambda' I_{it})\} g(0 | R_{it}) & \text{if } y_{it} = 0 \\ \{1 - \rho(\lambda' I_{it})\} g(h_{it} | R_{it}) & \text{if } y_{it} > 0 \end{cases} \quad (\text{B2})$$

The probability ρ_i depends on the characteristics (a subset of the explanatory variables) of country i and year t . Hence, ρ_{it} is written as a function of $\lambda'I_{it}$ where I_{it} is the vector of zero-inflated (ZI) covariates and λ is the vector of ZI coefficients to be estimated.

A probit function [using the same explanatory variables as described in Equation (1) in the paper] is specified as the ZI link function; it relates the product $\lambda'I_{it}$ (which is scalar) to the probability ρ_{it} . We thus estimate the frequency of hydrometeorological disasters using a negative binomial zero-inflated (NBZI) regression model. In the study of Vuong (1989), results revealed significant positive test statistics, which favor the ZI models over the standard NB count regression models. This means that the ZI method is necessary given the preponderance of zeroes of the dependent variable.

This model can determine whether the zero-observed dependent variable can correspond to countries that, in a particular year, had zero probability of having a disaster or a country that had a positive probability of a disaster but, due to random conditions in that year, experienced no disaster and consequently also had a zero dependent variable (Vuong, 1989).

3. Method 3: Cointegration.

First, we have this model with the coefficient of time dummies (yt) and the series of atmospheric CO2 (xt). This can be expressed as

$$y_t = \beta_0 + \beta_1 \cdot x_t + \mu_t \quad (\text{B3})$$

where:

$$\begin{array}{ll} \beta_0, \beta_1 & = \text{parameters and} \\ \mu_t & = \text{stochastic error term.} \end{array}$$

To simplify, we assume an autoregressive model AR(1):⁹

$$\mu_t = \theta_1 \mu_{t-1} + \varepsilon_t \quad (\text{B4})$$

In particular, we can estimate Equation (B4) using ordinary least squares (OLS) and using the unrestricted autoregressive distributed lag (ARDL) model, in which the lag lengths are set to eliminate the residual autocorrelation, an ARDL(1,1) model. From Equations (B3) and (B4), we have

$$y_t - \beta_0 - \beta_1 \cdot x_t = \mu_t$$

and

$$y_{t-1} - \beta_0 - \beta_1 \cdot x_{t-1} = \mu_{t-1}.$$

Using both expressions and Equation (B4),

$$y_t - \beta_0 - \beta_1 \cdot x_t = \theta_1 (y_{t-1} - \beta_0 - \beta_1 \cdot x_{t-1}) + \varepsilon_t,$$

and by rearranging the following terms

$$y_t = (\beta_0 - \theta_1 \beta_0) + \theta_1 y_{t-1} + \beta_1 x_t + \theta_1 \beta_1 x_{t-1} + \varepsilon_t,$$

and

$$y_t = \delta + \theta_1 y_{t-1} + \varphi_0 x_t + \varphi_1 x_{t-1} + \varepsilon_t \quad (\text{B5})$$

where $\delta = (\beta_0 - \theta_1 \beta_0)$, $\varphi_0 = \beta_1$, and $\varphi_1 = -\theta_1 \beta_1$. Equation (B5) is an unrestricted autoregressive distributed lag model, ARDL (1, 1).

⁹ We also tried with AR(2) but the additional parameters were not significant.

To obtain the error correction model (ECM) form, we use the next two equalities:¹⁰

$$y_t - \theta_1 y_{t-1} = \Delta y_t - (\theta_1 - 1)y_{t-1}$$

$$\varphi_0 x_t + \varphi_1 x_{t-1} = \varphi_0 \Delta x_t + (\varphi_0 + \varphi_1)x_{t-1}$$

where $\Delta y_t = y_t - y_{t-1}$ and $\Delta x_t = x_t - x_{t-1}$. We then use both equalities from Equation (B3), and then rearrange the following terms:

$$\Delta y_t = \delta + \varphi_0 \Delta x_t + (\theta_1 - 1)y_{t-1} + (\varphi_0 + \varphi_1)x_{t-1} + \varepsilon_t$$

$$\Delta y_t = \delta + k_0 \Delta x_t + \gamma_1 y_{t-1} + \gamma_2 x_{t-1} + \varepsilon_t \quad (B6)$$

where $k_0 = \varphi_0$, $\gamma_1 = \theta_1 - 1$ and $\gamma_2 = (\varphi_0 + \varphi_1)$.

We estimate Equation (B6) using the OLS method. From (B6), the estimator of the cointegrated coefficient is given by the long-run solution:

$$\hat{\beta}_1^* = -\frac{\hat{\gamma}_2}{\hat{\gamma}_1} \quad (B7)$$

4. Method 4: Vector error correction model and Johansen test.

In a bivariate model with y_t and x_t variables, there exist a β_0, β_1 such that $y_t - \beta_0 - x_t \beta_1 = \mu_t$ is stationary although x_t and y_t may be non-stationary series. This means that the two variables are cointegrated or have a stationary long-run relationship, albeit they are non-stationary series when taken individually.

A vector autoregressive model with l lags can be represented as shown in Equation (B8)

$$z_t = \rho_1 z_{t-1} + \rho_2 z_{t-2} + \dots + \rho_p z_{t-l} + \varphi \tau_t + \varepsilon_t \quad (B8)$$

where:

$$\begin{aligned} z_t &= \begin{pmatrix} y_t \\ x_t \end{pmatrix} &&= && 2 \times 1 \text{ vector of non-stationary variables} \\ \tau_t &= && && \text{vector of deterministic variable, and} \\ \varepsilon_t &= && && 2 \times 1 \text{ vector of identically and normally distributed errors with} \\ &&&&& \text{mean zero and non-diagonal covariance matrix } \Sigma. \end{aligned}$$

Given that the variables are co-integrated, Equation (B8) can be represented by an equilibrium correction model shown in Equation (B9) below:

$$\Delta z_t = \eta \omega z_{t-l} + \sum_{i=1}^{l-1} \Gamma_i \Delta z_{t-i} + \delta \cdot t + \nu + \varepsilon_t \quad (B9)$$

where:

$$\begin{aligned} \eta, \omega &= && \text{key coefficients,} \\ \omega &= && 2 \times r \text{ matrix of cointegrating vectors that explain the long-run} \\ &&& \text{relationship of the variables,} \\ \eta &= && 2 \times r \text{ matrix that explains the long run disequilibrium} \\ &&& \text{of the variables, and} \\ \nu, t &= && \text{deterministic trend component.} \end{aligned}$$

¹⁰ Developing the right sides of both equalities directly reaches the left sides.

Note that for cointegration to exist, matrices η and ω should have reduced rank r , where $r < 2$. The identification of the cointegrating vector uses the maximum likelihood method developed by Johansen (Johansen,1995).

Table B1. Johansen test for cointegration

Rank (r)	Johansen Test	Critical Value 1%
0	23.434***	16.31
1	4.1736	6.51

Notes: * and *** refer to value/s that are significant at the 1% level.

Table B2. Cointegration analysis of intense disasters-CO₂ series: Short-run and long-run parameters

Parameter	Hydrometeorological Disasters	
	Short Run	Long Run
CO ₂ level	0.0232 [0.00289]	0.0180*** [0.0070]

Notes: *** refers to values that are significant at the 1% level. Values that are in brackets are standard errors.

5. Method 5: Estimation of Granger causality test.

To test causality in the long run, we use Equation (B9), and then define

$$z_t = \begin{pmatrix} y_t \\ x_t \end{pmatrix}$$

We then estimate that the best model for our variables is the model that has five lags (i.e $l = 5$). Thus,

$$\Delta z_t = \eta \omega' z_{t-4} + \sum_{i=1}^3 \Gamma_i \Delta z_{t-1} + \delta \cdot t + \nu + \varepsilon_t$$

We verify whether the coefficients of $\{\Gamma_i\}_{i=1}^4$ in each element y_t are jointly different at zero. If this fact can be rejected, then it will prove causality in the long run. Table B3 below shows the results. When we test the causality from CO₂ to the coefficient of the time dummy variables, it is possible to reject the null hypothesis at 1% level. Conversely, when we test the causality from the coefficient of time dummy time variables to CO₂, it is not possible to reject the null hypothesis. Therefore, we conclude that the direction of causality must go from atmospheric CO₂ accumulation to hydrometeorological disasters.

Table B3. Test of Granger causality in the long run

Parameter	y_t	x_t
Hypothesis	CO ₂ → Coefficient of time dummy variables	Coefficient of time dummy variables → CO ₂
H_0	$\Gamma_1 = 0$	$\Gamma_1 = 0$
	$\Gamma_2 = 0$	$\Gamma_2 = 0$
	$\Gamma_3 = 0$	$\Gamma_3 = 0$
	$\Gamma_4 = 0$	$\Gamma_4 = 0$
Test F	7.6300*	5.1300
p-Value	0.009	0.2741

Note: * refers to values that are significant at 10% level.

6. Method 6: Estimating the elasticities of intense disasters with respect to CO₂ level (1970–2016).

We estimate the elasticities of the disasters, which were evaluated at the average values of the variables for the period 1970–2016. The coefficient values of the time dummy variables (y_t) are related to atmospheric CO₂ (x_t) as follows:

$$y_t = \beta_0 + \beta_1 \cdot x_t + \mu_t.$$

The elasticity of y_t with respect to y_t is

$$\frac{\partial \ln y_t}{\partial \ln x_t} = \frac{\partial y_t}{\partial x_t} \cdot \frac{x_t}{y_t} = \hat{\beta}_1 \cdot \frac{x_t}{y_t}.$$

In the case of CO₂, the $\hat{\beta}_1$ estimated is 0.0180, the mean sample value of CO₂ is 360.2134, and the mean sample value of y_t is 0.7117. Hence, the elasticity of y_t with respect to x_t when evaluated at the mean sample values is

$$\frac{\partial \ln y_t}{\partial \ln x_t} = 0.0180 \cdot \frac{360.21}{0.7117} = 9.1007.$$

Using the data for 1970–2016, the effect of y_t on the number of hydrometeorological disasters is 0.7117. Moreover, the number of intense hydrometeorological disasters of a “representative country” is 0.723. Hence, given that the dummy variables are all equal to one, the elasticity of the number of disasters of a representative country with respect to y_t is

$$\frac{\partial \ln H_t}{\partial \ln y_t} = \frac{y_t}{H_t} = 0.984.$$

Hence, using the chain rule, the elasticity of disasters of representative country with respect to CO₂ is

$$\frac{\partial \ln H_t}{\partial \ln x_t} = \frac{\partial \ln H_t}{\partial \ln y_t} \cdot \frac{\partial \ln y_t}{\partial \ln x_t} = 9.1007 \cdot 0.984 = 8.96. \quad (\text{B10})$$



Philippine Institutions and Complex Institutional Arrangements for Climate Change Adaptation in Agriculture

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Abstract

Addressing climate change necessitates creating new, or building the capacity of old, institutions. Institutions are vital tools that determine the intensity by which climate change considerations are incorporated into the decision-making process, designs, and plans. This article aims to illustrate that it is necessary to understand the institutional environment where the climate change adaptation (CCA) endeavors will be implemented such that local CCA policies, plans, and programs can be implemented effectively. The paper also intends to demonstrate that, along with the scientific and technological discussions, institutional conversations should be among the initial vital steps in CCA planning, and that the institutional dimension should be the foundation of broader reforms toward an effective CCA implementation. The paper accomplished this by investigating the conditions in the local agriculture and CCA in the Philippines. The paper applied the Institutional Environment Matrix as the main analytical framework.

The analysis showed that the existing institutional dynamics in the Philippines have impacted the effectiveness of the introduced CCA policies and efforts. The Local Government Code of the Philippines had counterproductive interplays with other institutional rules; first in agriculture, and afterwards, in CCA. The Code has devolved tasks to the local governments, provided local government units with extensive authority over their jurisdictions, and improved autonomy in local governance. However, it lacks the arrangements that would create (dis)incentives for individual and collective actions (i.e., rewards and penalties, payoffs on actions). Likewise, institutional mechanisms to support the devolution of government services are wanting. Such institutional environment in local governance has curtailed the effectiveness of local agricultural policies and the efficient implementation of new CCA policies.

This article advocates that analyzing the institutional environment where the CCA endeavors will be implemented will enable policy makers and CCA planners to understand better and to have deeper perception of the interlinkages between and among institutional arrangements. In the case of the Philippines, if the local agricultural institutional environment was considered in the design and implementation of the CCA policies, institutional support mechanisms that can address the existing issues and concerns in local agriculture may have been incorporated into these policies. Such action may have helped implementers to avoid the same difficulties in operationalizing CCA initiatives. Accordingly, the paper analyzed how CCA is operationalized through an institutional lens, and presented how institutional analysis is important in policy making. It further demonstrated the complexity of institutional linkages and raised the conversation on the institutional dimension of CCA.

Keywords: Institutional environment; local climate change adaptation; institutional dimension of climate change adaptation; institutional interplays; Philippine local agricultural adaptation

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Introduction

Institutions are central in the transformation and development of long-term adaptive capacity and resilience to climate change of systems. Specifically, policy and regulatory tools are the “enabling factors” that determine the intensity by which climate change considerations are mainstreamed into the decision-making process, designs, and plans for sustainable development (Berman, Quinn, & Paavola 2012; Boyle, Cunningham, & Dekens, 2013). Addressing climate change necessitates creating new, updating the old, or building the capacity of existing institutions. Although actual institutional responses to climate change are being realized, the adjustment in the institutional landscape and the operationalization of institutional actions toward the endeavor have been slow and limited. Most institutions have been established to address the problems of the past, and they need to be upgraded to confront the complexity of future climate scenarios effectively (United Nations Development Programme, 2011).

However, the existing legal and institutional frameworks are inadequate to facilitate an effective institutional response to climate change (Cruz et al., 2007; Tan & Pereira, 2010). The poor institutional capacity, weak institutions, and the need for institutional reforms have contributed to the vulnerability and lack of resilience in most, if not all, developing countries (Wilbanks et al., 2007; Rydge, Jacobs, & Granoff, 2015). These conditions validate the significance of synergized institutional, scientific, and technological approaches in building climate resilience in systems. The task, therefore, needs a multidimensional perspective.

Adaptation endeavors should encompass generating scientific and technological plans and designs and the means by which these sets of information and outputs will be integrated into the institutional environment (IE) where the adaptation measure will operate (Jentoft & Chuenpagdee, 2009; FitzGibbon & Mensah, 2012; Cuevas, Peterson, Robinson, & Morrison, 2016; Cuevas, 2018). Accordingly, this paper aims to show that in order to be effective in implementing local climate change adaptation (CCA) policies, plans, and programs, planners and policy and decision makers need to understand the IE where their respective CCA initiatives will be implemented.

IE is defined as the array of institutions that influence the behaviors and decisions of the actors within the domain of interest; in this case, agriculture and CCA. Along with the scientific and technological discussions, institutional conversations should be among the initial vital steps in CCA planning; the institutional dimension should be the foundation of the reforms toward an effective CCA implementation. Understanding the IEs enables stakeholders to analyze better the existing and potential problems in the IE, and to have a deeper and broader

perception of the interlinkages between and among institutional arrangements. Through an IE analysis, the present paper provides a good overview of the institutional interplays; that is, determining what arrangement and from which institution is complementary, contradicting, overlapping, or in conflict with another.

The paper is structured as follows. Section 2 presents a brief introduction of the agriculture and climate change conditions in the Philippines, thereby justifying the choice of study area. This is followed by the discussion of the methodology and limitations of the paper in Section 3. Section 4 details the first part of the analysis—the composition of the IEs of agriculture and CCA at the local scale. Section 5 illustrates the institutional interplays in the IEs, and Section 6 provides the concluding remarks of the paper. Fundamentally, the paper aims to stimulate the discussion on the institutional dimension of CCA. In doing so, it bridges the gap between planning and operationalization of CCA endeavors through an institutional lens.

Overview of Agriculture and Climate Change Adaptation in the Philippines

The contribution of agriculture to the Philippine economy has dwindled over the last 70 years. Its share of the country's GDP has been sliced from 30% in 1946, to 20%, 14%, and 7% in 1970, 2000, and 2018, respectively. Nevertheless, the sector remains a significant source of employment, securing around a quarter of all jobs in the country in 2018. Its share was even greater than that of the manufacturing sector (19%) during the same year (PSA, 2020a, 2020b).

Through the years, the declining performance of agriculture has been attributed to a combination of factors. The central causes of the sector's deterioration are the weaknesses in institutions and in governance within the agricultural bureaucracy, i.e., overcentralization, politicization of the bureaucracy, lack of clear organizational framework and organizational cohesion, weak technical and managerial capability, unclear communication lines, unstable budget, and corruption (David, 1995; Habito & Briones, 2005; David et al., 2012; OECD, 2017).

Another significant factor that directly impacts Philippine agricultural productivity is the inefficient provision of agricultural extension services. These services include the activities concerned with delivering information and services to agricultural stakeholders for capacity development (i.e., technical, organizational, management skills) and for improving the livelihood and well-being of agricultural stakeholders, particularly those in the rural areas (Ani & Correa, 2016). Essentially, agricultural extension is characterized by low levels of financing; fragmented institutions; lack of institutional coordination; disharmony of programs; overlapping

functions and activities of institutions; human resource issues; partisan politics and political interference, among others (Cidro & Radhakrishna 2003; Ocenar, Brillantes, Curthbertson, & Tumanut, 2004; Ani & Correa 2016; OECD, 2017).

The meager agricultural production in the Philippines is now further threatened by climate change. Agriculture highly depends on climatic conditions, and hence is extremely sensitive to its variations. Through the changing rainfall patterns, rising temperatures, increasing occurrence of intensified typhoons, and the like, climate change has been, and will continue to threaten the sector's productivity and overall performance (e.g., climate change-induced productivity shocks) (Chen, et al., 2016; Cruz et al., 2017; Lewis, Monem, & Impiglia, 2018).

Meanwhile, the Philippines is one of the countries highly vulnerable to climate change. In 2018, it ranked 5th in the world in terms of the most at-risk to climate change (i.e., Long-Term Climate Risk Index), and 4th with regard to countries most affected by extreme weather events in the years 1998–2017 (Eckstein, et al., 2019). With bleak climate projections, future conditions are likely to worsen in the country. Under the representative concentration pathway (RCP) 8.5 (high-emission scenario), temperatures can rise as high as 2.3 °C and 4.1 °C, by mid- and end of the 21st century, respectively. Likewise, under the same RCP 8.5 scenario, rainfall might decrease up to 40% by mid-21st century, whereas sea level is expected to rise by 20 CM by end of the century. Similarly, tropical cyclones are anticipated to intensify further (Philippine Atmospheric, Geophysical, and Astronomical Services Administration [PAGASA], 2018).

The Philippines recognizes the importance of addressing and adapting to climate change, and has enacted laws toward this goal. Two of the most influential legislation on the concern are the Climate Change Act of 2009 (hereafter referred to as the Act) and the Philippine Disaster Risk Reduction and Management Act of 2010. The Act institutionalized climate change and CCA mainstreaming into the national and local government policies, plans, and programs. It also created the primary policy-making body of the government on climate change concerns, the Climate Change Commission. Meanwhile, the Philippine Disaster Risk Reduction and Management Act established the CCA and disaster risk reduction management (DRRM) agenda in government processes such as policy formulation, socioeconomic development planning, budgeting, and governance.

In recent years, the Philippines has also established the institutional foundations linking climate change to agriculture. To illustrate, both the Republic Act (RA) No. 8435 (Agriculture and Fisheries Modernization Act [AFMA] of 1997) and the Climate Change Act, the main laws governing the rules in agriculture and climate

change, respectively, acknowledged this connection. Section 16 of the AFMA has provisions concerning “Global Climate Change”, whereas Section 9(f) of the Climate Change Act identifies agriculture among the climate-sensitive sectors. The Department of Agriculture (DA), the lead government agency in the sector, has also initiated efforts toward implementing CCA. In 2010, it created the Climate Change Program Office under the Office of the Undersecretary for Policy and Planning. In 2011, it issued a policy and implementation program to guide stakeholders in addressing climate change issues. In 2013, the DA issued a memorandum on “Mainstreaming Climate Change in the DA Programs, Plans and Budget”. This memorandum likewise led to the creation of the Adaptation and Mitigation Initiative in Agriculture.

The Philippines is an interesting case for an institutional environment analysis. For one, it is in a unique position to provide robust sets of information on the interactions and interplays among the existing institutions operating in agriculture and has introduced sets of institutional rules in CCA. Furthermore, it has an agricultural sector that is defined by problematic agricultural bureaucracy, weak institutions, and a challenging extension services system on one hand. On the other, the Philippines has been institutionalizing climate change-related laws and policies in the past decade; laws in which the effects can now be assessed and analyzed.

Methods and limitations

The author conducted a desk research; particularly, it examined around 40 relevant CCA and agriculture laws and policies, investigated the functions and mandates of 25 organizational institutions, and studied approximately 80 peer-reviewed papers, government reports, and grey literature on the topics.

Analytical Framework

This paper applied the Institutional Environment Matrix (IEM) framework, developed by Cuevas, Peterson, and Morrison (2014), in analyzing the IEs of agriculture and CCA and in examining the institutional interactions within these environments. Although there are other frameworks for analyzing institutions, they are not suitable to address the objectives of this research, which is to analyze all forms of institutions—rules, social structures (customs, norms, practices), and organizations.

To illustrate, the Adaptation, Institutions and Livelihoods (AIL) framework developed by Agrawal (2008) focuses only on organizational institutions; it examines relationships among public, private, and civil society institutions. It is a tool used primarily to analyze organizational partnerships for facilitating adaptation. Meanwhile, the Adaptive Capacity Wheel framework of Gupta et al. (2010) defines institutions as rules, customs,

and norms—factors that influence the individual and collective behaviors and actions, as well as the adaptive capacities of societies. Although the Advocacy Coalition Framework of Sabatier and Weible (2007) does define institutions as rules, social structures, and organizations, its main aim is to assess the political conflicts and technical disputes of multiple actors. It is not meant to study IEs, institutional arrangements, and the functional interdependencies of institutions, which are the elements needed for this research.

The IEM, on the other hand, considers rules, social structures, and organizations as components of the IE; it is also designed for examining complex IEs and for determining the institutional fit of CCA responses. The IEM framework has a dual layer design—IE and institutional matrix (IM). The first layer (i.e., IE)

inventories the institutions that interact within the system or setting. Meanwhile, the IM concerns itself with the arrangements: (1) linking the institutions, (2) determining institutional functions, (3) influencing institutional interactions, and (4) determining institutional interplays. The matrix depends on the institutions identified in the IE; these institutions comprise the vertical (column) section of the IM. On the other hand, the horizontal (row) section is composed of the various functions of institutions; they are the classifications by which the institutional arrangements are organized in the IM cells. Essentially, the matrix provides a structure for analyzing institutional interplays in relation to the general institutional functions: reducing uncertainty, connecting individuals to society, fostering adaptive capacity, and mobilizing resource utilization (Table 1).

Table 1. Institutional matrix structure: Institutional functions by type of institutions

INSTITUTIONAL FUNCTIONS	Description	TYPES OF INSTITUTIONS		
		Rules	Social Structures	Organizations
<i>Reduces uncertainty</i>				
Establishes systems of power and authority	Actors and actions involved in decision making; who has the authority and what kind of authority	●	●	●
Identifies inclusions and exclusions	Scope and jurisdiction of actors (who) and actions (what) allowed and constrained	●	●	●
Creates rights and entitlements	Claims, privileges, etc. to resources, i.e., access rights, management rights	●	●	
Provides structure in procedures and processes	Sets of rules or agreements that preside over how the activities are implemented.	●	●	●
<i>Connects individuals to society</i>				
Converts personal values into social norms and shared beliefs	Social principles, beliefs, and philosophies	●	●	●
Influences and transforms individual acts and expectations into collective actions	Plans and programs for collective efforts and actions	●	●	●
Creates (dis)incentives for individual and collective actions	Rewards and penalties; payoffs on actions	●	●	●
Coordinates individual or collective behaviors	Management of multiple efforts	●	●	●
<i>Fosters adaptive capacity</i>				
Defines information systems	Provision of information (who, what, when, where, how and for whom)	●	●	●
Mediates influence of external interventions	Access to and management of outside resources (how, what, when, where)	●	●	●
<i>Mobilizes resource utilization</i>				
Means of delivery of external resources	Actors facilitating access to outside resources (who and for whom)			●
Determines transaction costs of activities and decisions	Integration of multiple efforts; internal costs (financial or otherwise)	●	●	●
Allocates resources	Provision of resources (who, what, when, where, how and for whom)	●	●	●

Source: Cuevas et al. (2014)

Based on the design of the matrix, users can analyze the system of institutional arrangements—operational and collective-choice rules and governance arrangements—in the IE (Table 2). The vertical assessment of the matrix shows the different arrangements that enable an institution to perform its functions. It is possible for an institution to fulfill only one or all functions, depending on the arrangements it provides. Meanwhile, the horizontal assessment enables the users to examine the functional interdependencies of institutions, and/or the linkages across institutions. For example, by laying out the different arrangements that establish the system of power and authority provided by each institution, one can examine whether an institution contradicts or complements the authority established by another. Essentially, this design enables a structured analysis of institutional interplays—interactions and reactions

between and among institutions that build institutional linkages, relationships, and interdependencies (Cuevas et al., 2014).

Possible interactions among institutions include *complementary interactions*, which denotes institutions benefitting from one another and functioning better because of the creation or existence of the other. Conversely, *counterproductive interactions* imply institutions that destabilize and inhibit one another from carrying out their respective functions effectively. *Neutral interactions*, on the other hand, indicate that institutions neither improve nor worsen the functioning of others; they simply exist together in the same IE.

When institutions are incompatible or institutional arrangements are not attuned with each other,

Table 2. Institutional Environment Matrix framework for adaptation analysis

INSTITUTIONAL FUNCTIONS	TYPES OF INSTITUTIONS							
	Rules (R)			Social Structures (SS)		Organizations (O)		
	R1	R2	R3	SS1	SS2	O1	O2	O3
<i>Reduces uncertainty</i>								
Establishes systems of power and authority	IA	IA	IA	IA	IA	IA	IA	IA
Identifies inclusions and exclusions	IA	IA	IA	IA	IA	IA	IA	IA
Creates rights and entitlements	IA	IA	IA	IA	IA	IA	IA	IA
Provides structure in procedures and processes	IA	IA	IA	IA	IA	IA	IA	IA
<i>Connects individuals to society</i>								
Converts personal values into social norms and shared beliefs	IA	IA	IA	IA	IA	IA	IA	IA
Influences and transforms individual acts and expectations into collective actions	IA	IA	IA	IA	IA	IA	IA	IA
Creates (dis)incentives for individual and collective actions	IA	IA	IA	IA	IA	IA	IA	IA
Coordinates individual or collective behaviors	IA	IA	IA	IA	IA	IA	IA	IA
<i>Fosters adaptive capacity</i>								
Defines information systems	IA	IA	IA	IA	IA	IA	IA	IA
Mediates influence of external interventions	IA	IA	IA	IA	IA	IA	IA	IA
<i>Mobilizes resource utilization</i>								
Means of delivery of external resources						IA	IA	IA
Determines transaction costs of activities and decisions	IA	IA	IA	IA	IA	IA	IA	IA
Allocates resources	IA	IA	IA	IA	IA	IA	IA	IA

Note: IA = institutional arrangements

Source: Cuevas et al. (2014)

contradicting relationships form. These links result in conflicts among institutions and in clashes among their functionalities. In instances when institutions have similar mandates, the *overlapping interactions* among them generally lead to disagreements on jurisdictions. Conditions worsen when relationships are *redundant* due to the complete duplication of most or all institutional functions (Cuevas et al., 2014).

Limitations

The primary step in determining how the introduction of CCA institutions impact the agriculture sector is to understand each individual IE. Examining the IEs of

the agriculture sector and CCA separately enables one to comprehend the core issues affecting CCA efforts in agriculture. Hence, the need to identify the different institutions in both environments (Tables 3 and 4).

The agriculture sector has numerous institutional issues; each issue is complicated and would need intensive analysis. To achieve the objective of illustrating the need to understand the institutional environment where CCA endeavors will be implemented, the paper focuses on selected issues. The different aspects of agriculture were examined to determine which areas are relevant to CCA efforts.

Table 3. Selected institutional rules in agriculture and climate change adaptation

Agriculture	Climate Change Adaption
Presidential Decree No. 717 of 1975 - Provided credit and financing system for agrarian reform beneficiaries through banking institutions	RA No. 9729 Climate Change Act
Executive Order No. 116, s. 1987 - Reorganization Act of the Ministry of Agriculture and Food	RA No. 10121 Philippine Disaster Risk Reduction and Management Act of 2010
RA No. 6657, Comprehensive Agrarian Reform Law of 1988	2010 –2022 National Framework Strategy on Climate Change
RA No. 7607, Magna Carta for Small Farmers of 1992	RA No. 10174 - People's Survival Fund of 2011
RA No. 8435, Agriculture and Fisheries Modernization Act of 1997	National Climate Change Action Plan 2011–2028
RA 8532, Strengthening the Comprehensive Agrarian Reform Law of 1998	Executive Order No. 43, s. 2011 - Pursuing Our Social Contract with the Filipino People Through the Reorganization of the Cabinet Clusters
RA No. 8550, Philippine Fisheries Code of 1998	RA No. 10639 Free Mobile Disaster Alert Act of 2014
RA No. 9168, Philippine Plant Variety Protection Act of 2002	RA No. 10692 PAGASA Modernization Act of 2015
RA No. 9700, CARP Extension with Reform of 2009	DBM National Budget Memorandum No.118 - Adoption of the Budget Priorities Framework in the Preparation of the FY 2014 Agency Budget Proposals
RA No. 10000, Agri-Agra Reform Credit Act of 2009	DBM-CCC JMC No. 2013-01 Guidelines in Tagging/Tracking Government Expenditures for Climate Change in the Budget Process
RA No. 10068, Organic Agriculture Act of 2010	DBM Local Budget Memorandum No. 2014-68 FY 2015 Internal Revenue Allotment Level and Other Local Budget Preparation Matters
Rice Mechanization Program, 2011	DBM-CCC-DILG JMC No. 2014-01 Tagging/Tracking Climate Change Expenditures in Local Budget
Food Staples Sufficiency Program, 2011	DBM-CCC-DILG JMC No. 2015-01 - Revised Guidelines for Tagging/Tracking Climate Change Expenditures in the Local Budget (Amending JMC-2014-01, Dated August 7, 2014)
RA No. 10601, Agricultural and Fisheries Mechanization Law of 2013	DBM-CCC Joint Memorandum Circular No. 2015-01 - Revised Guidelines for Climate Change Expenditure Tagging amending JMC No. 2013-01
RA No. 10654, Amendment to the Philippine Fisheries Code, 2014	DBM Local Budget Memorandum No. 70 issued June 2015 FY 2016 Internal Revenue Allotment Level and Other Local Budget Preparation Matters
Agro-industry Modernization Credit and Financing Program	DILG MC No. 2008-69 - Encouraging All Local Chief Executives and Sanggunians to Implement Climate Change Adaptation and Disaster Risk Reduction Measures
Comprehensive Agriculture Loan Fund	DILG MC No. 2008-123 - Mobilizing Local Actions to Address the Impacts of Climate Change

Table 3 (continued)

Agriculture	Climate Change Adaption
Strategic Agriculture and Fishery Development Zones	DILG MC No. 2008-161 Trainor's Training on Mobilizing Local Actions to Address the Impacts of Climate Change
DA Administrative Order No. 6 s.1998	DILG MC No. 2012-73 – Utilization of Local Disaster Risk Reduction and Management Fund DILG MC No. 2014-135 Guidelines on the Formulation of Local Climate Change Action Plan DILG MC No. 2015-77 Guidelines on Mainstreaming Climate Change Adaptation and Disaster Risk Reduction in Local Development Planning Presidential Decree No. 78 Presidential Decree No. 1149 Executive Order No. 128 DENR Administrative Order No. 97-11 DBM Memorandum March 15, 2012

Table 3 (continued)

<i>Note:</i>	CARP = Comprehensive Agrarian Reform Program	DBM = Department of Budget and Management
	JMC = joint memorandum circular	DENR = Department of Environment and Natural Resources
	CCC = Climate Change Commission	DILG = Department of Interior and Local Government
	MC = memorandum circular	FY = Fiscal year
	DA = Department of Agriculture	RA = Republic Act
	PAGASA = Philippine Atmospheric, Geophysical and Astronomical Services Administration is the National Meteorological and Hydrological Services	

Table 4. Selected institutions in agriculture and climate change adaptation

Agriculture	Climate Change Adaption
Department of Agriculture	Climate Change Commission
Bureau of Soils and Water Management	Office of Civil Defense
Bureau of Fisheries and Aquatic Resources	National Disaster Risk Reduction and Management Council
Bureau of Animal Industry	Department of Interior and Local Government
Bureau of Plant Industry	Department of Budget and Management
Philippine Center for Postharvest Development and Mechanization	Philippine Atmospheric Geophysical and Astronomical Service Administration
Bureau of Agricultural Research	University of the Philippines Nationwide Operational Assessment of Hazards
Bureau of Agricultural and Fisheries Engineering	Manila Observatory
Bureau of Agriculture and Fisheries Standards	Mines and Geoscience Bureau
Philippine Rice Research Institute	
National Irrigation Administration	
Philippine Council for Agriculture and Fisheries	
Philippine Crop Insurance Corporation	
Agricultural Credit Policy Council	
Agricultural Training Institute	
National Food Authority	

Initial analysis revealed the relevant linkages among the institutions within the agriculture and CCA IEs in relation to extension services, funding and finance, and research and development and technology (R&D and technology). The IEs and the existing network of institutions related to these concerns (i.e., extension services, funding and finance, and R&D and technology) proved to be complex and extensive (Figure 1).

Based on Figure 1, the R&D and technology concern will even encompass those institutions involved in agrometeorological stations, information generation and dissemination, R&D networks, etc. Thus, the investigation was further narrowed to those concerns that directly affect local agriculture and CCA, and hence the focus on the extension services. Although local units are likewise affected by R&D and technology concerns,

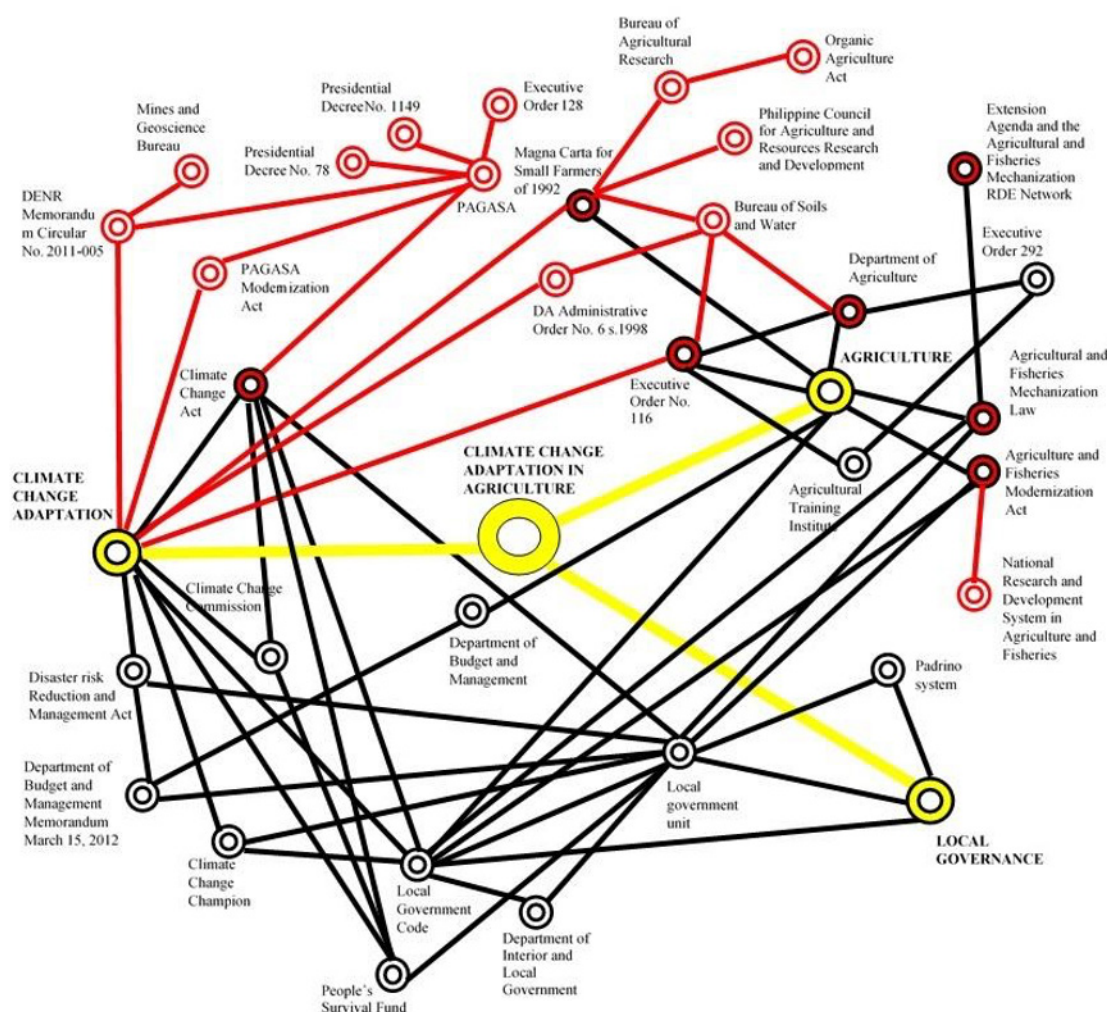


Figure 1. A framework for the disaster-climate relation

- Notes:**
- (1) The yellow circles and lines represent the IEs and linkages that comprise the local agricultural CCA in the Philippines. The red and black lines and circles indicate the institutions and linkages involved in R&D and technology and extension services, respectively. The circles with red fill represent the institutions involved in both concerns. Notice that although local units are likewise affected by R&D and technology concerns, most of the institutional interactions in this area do not involve the local governance institutional environment.
 - (2) The figure is only a partial and not a complete illustration of the network of all institutions. The design of the figure was borrowed from Cuevas (2018).
 - (3)

DA	=	Department of Agriculture
DENR	=	Department of Environment and Natural Resources
PAGASA	=	Philippine Atmospheric, Geophysical and Astronomical Services Administration is the National Meteorological and Hydrological Services
RDE	=	research, development, and extension

most of the institutional interactions in this area are at the national scale.

Meanwhile, the issues on extension services also touch on some funding and financial concerns. Still, the number of institutions involved in extension services is extensive. Thus, due to time and other constraints, analysis was not exhaustive. That is, only those selected few that will give sufficient information to achieve the objective of the research were featured; not all institutions and arrangements were analyzed. Lastly, provided that the Philippine agriculture sector comprises both agriculture and fisheries, the analysis was limited to the former to simplify the already complex nature of the analysis.

Results: Institutional Environments in Agriculture and Climate Change Adaptation

IE: Local Agriculture

Considering the limitations of the research, the IE of the local agriculture in the Philippines comprises the rules pertaining to agriculture, such as the Agriculture and Fisheries Modernization Act of 1997 (AFMA), Agricultural and Fisheries Mechanization Law of 2013 (AFMech), and the Executive Order (EO) 116 s. 1987 (Table 5). The AFMA is the key law on agriculture and fisheries production in the Philippines. Specifically, it stipulates the policy framework and support measures that reinforce a technology-based and market-driven agricultural production in the country. The AFMech,

on the other hand, was enacted to modernize Philippine agriculture through mechanization. It intends to develop partnerships for research and development between and among the government, academic institutions, farmer organizations, civil society, and other private units.

EO No. 116, also known as the “Reorganization Act of the Ministry of Agriculture and Food”, is the chief law that mandates the DA to promote agricultural development; provide the policy framework, public investments, and support services needed by the sector; and oversee and direct the planning, regulation, execution, and monitoring of programs and activities concerning agriculture and food production in the country. As part of the government system, the DA is also ruled by EO No. 292 or the Administrative Code of 1987. In particular, this is the rule that provides the key structures, procedures, functions, and rules of governance in the Philippines. The policy is also part of the agricultural IE, as it oversees how government agencies are organized, including the arrangements between the central and field offices of departments.

The IE for local agriculture is, likewise, composed of rules and organizations concerned with local government activities, specifically, the Local Government Code of 1991 (hereafter referred to as the Code). This law created a system of decentralization and gave local government units (LGUs) in the Philippines more powers, authority, responsibilities, and resources, and thereby greater autonomy.

Table 5. Institutional environment: Philippine agriculture and CCA at the local scale

INSTITUTIONAL SYSTEM: LOCAL AGRICULTURE- Agricultural Extension Services	Formal Rules	Social Structures	Formal Organizations
AGRICULTURE	Agriculture and Fisheries Modernization Act of 1997 Agricultural and Fisheries Mechanization Law of 2013 Executive Order 116, s. 1987 Executive Order 292 / Administrative Code of 1987 Local Government Code of 1991	<i>Padrino</i> system	Department of Agriculture Local government unit
CLIMATE CHANGE ADAPTATION	Climate Change Act of 2009 Philippine Disaster Risk Reduction and Management Act of 2010 Local Government Code of 1991 Department of Budget and Management Memorandum March 15, 2012	Climate change champion <i>Padrino</i> system	Climate Change Commission Local government unit Department of Interior and Local Government Department of Budget and Management

Note: *Padrino* system refers to “the norm or value system of political patronage where a person gives or gains favor, promotion, or political appointment through social (friendship) or familial affiliation, instead of merit and qualifications” (Cuevas et al., 2016 p. 53)

Lastly, this environment is also comprised of the social norm that is prevalent in local governance in the Philippines, the *padrino* (patronage) system, which is defined as “the norm or value system of political patronage where a person gives or gains favor, promotion, or political appointment through social (friendship) or familial affiliation, instead of merit and qualifications” (Cuevas et al., 2016 p. 53).

IE: Local Climate Change Adaptation

The IE of CCA encompasses the rules pertaining to climate change and the CCA-DRRM agenda in the Philippines. Hence, it involves the Act, the Philippine Disaster Risk Reduction and Management Act, and the People’s Survival Fund of 2011. The People’s Survival Fund is an amendment to the Act, and is primarily concerned with providing funding support or financial streams for CCA programs and projects at the local level. Through the Act, the Climate Change Commission is included in the IE.

Similar to the agricultural IE, the Code is involved in the local implementation of both CCA and DRRM. Accordingly, the LGU and the Department of Interior and Local Government are included in the local CCA IE,

given the latter’s mandate to supervise local governments and promote local autonomy in accordance with the Code. Also, the CCA IE covers the Department of Budget and Management, due to its role in the financial concerns of government units. In this particular case, it issued the department memorandum dated 15 March 2012 with the subject “Local Disaster Risk Reduction and Management Offices in Local Government Units”. This IE is also comprised of the climate change champion, which is “the identifiable political/administrative champion for climate change issues who symbolizes a social structure-based institution that can 1) form individual and social expectations, and 2) influence relations, interactions, behaviors, and the conduct of people” (Cuevas et al. 2016, p. 2054).

These institutions likewise interact with an IE of local governance, as can be seen by the identified institutions in both local agriculture and CCA IEs. In fact, local governance institutions and arrangements have vital roles and influences in the operationalization of local agricultural CCA. If institutional linkages will be plotted, then both the LGU and the Code would have the most links to other institutions in agriculture and CCA IEs (Figure 2). The relationships and interactions among

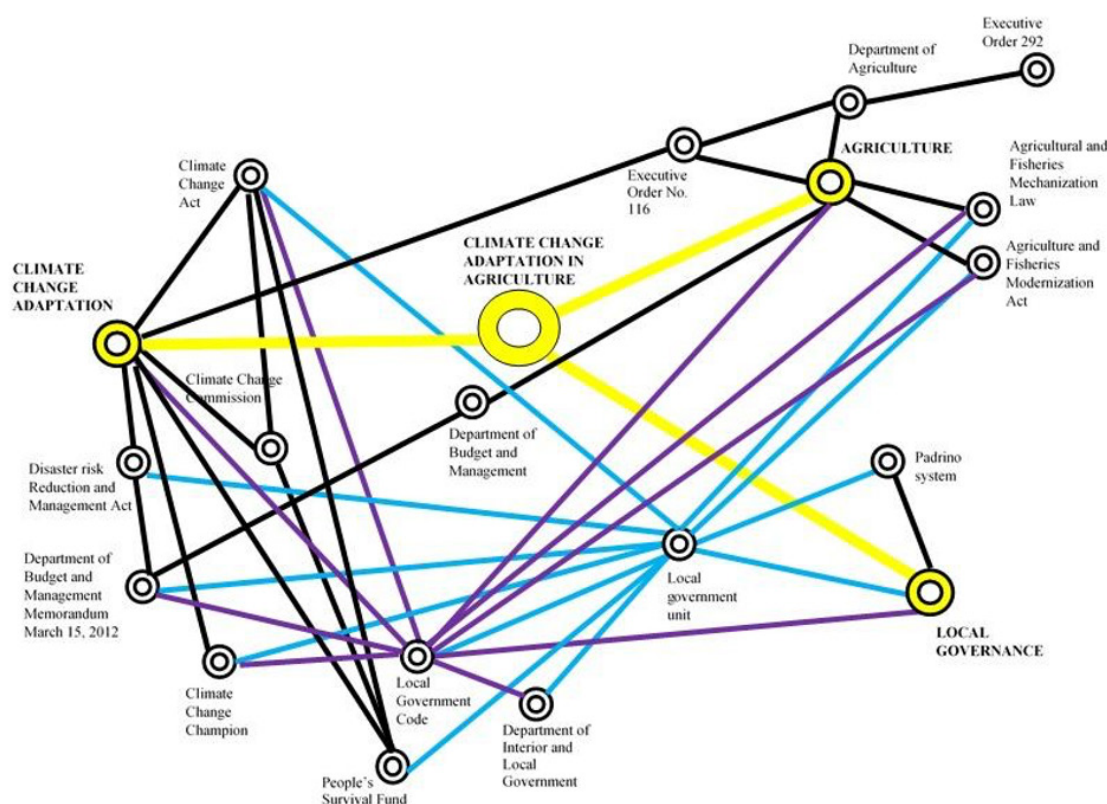


Figure 2. Climate change adaptation in agriculture: Network of institutions and IEs involved in extension services

- Notes:
- (1) The yellow circles and lines represent the institutional environments and linkages that comprise the local agricultural climate change adaptation in the Philippines. The blue lines indicate the linkages with the local government unit, whereas the violet lines signify the linkages with the Local Government Code. The black lines represent all the other linkages among institutions.
 - (2) The figure illustrates the institutions and linkages included in the analysis. It does not represent the network of all institutions involved in extension services. The design of the figure was borrowed from Cuevas (2018).

the network of institutions are intensively discussed in the next section.

Discussion: Institutional interplays in local agricultural climate change adaptation

Climate change adaptation is a relatively new endeavor that is being integrated into the existing agricultural institutional system. Although CCA has its own IE, its incorporation into the agricultural system indicates that it will also face the existing conditions affecting the agricultural IE. Thus, this section discusses first the agricultural IE, as it is imperative to understand the institutional interplays in this environment. Afterward, CCA will be included into the mix.

Interplays among National and Local Institutions in Agriculture: Devolution of Agricultural Extension Services

EO No. 116 has provided the DA with the power and authority over agricultural concerns in the Philippines, including providing extension services and training to farmers; it established the DA as an integral component in agriculture's IE. However, the extension services function of the DA has been completely affected when the Code was enacted. The Code is the legislation that has devolved the power, authority, resources, and responsibilities over local concerns from the national government to the LGUs (provincial, city, and municipal governments). Particularly, Section 17(b) of the Code decrees the agricultural support services function to the *barangays* (i.e., smallest administrative unit in the Philippines), and agricultural extension and onsite research services and facilities to municipalities and provinces.

The AFMA reestablished the authority of LGUs in local agriculture, such that LGUs “shall be responsible for delivering direct agriculture and fisheries extension services” (Section 90 AFMA, 1997). Meanwhile, Article 7 of the AFMech outlines applied research, extension, dispersal, management, and regulation, along with agricultural engineering endeavors, to be among the LGUs' responsibilities (Sections 28 and 29).

When agricultural extension services were devolved to the LGUs, it resulted in a number of difficulties, which made the Code counterproductive with the other institutions in the agricultural IE. First, with two institutions leading the initiatives, the system of authority over agricultural concerns was compromised. The DA is the central authority on agricultural concerns in the country and has its own key result areas that guide its goals and activities. These key result areas are set by the DA, which are independent from the goals and objectives of other institutions. These key result areas are the basis of the department's policies, programs, and projects (Cuevas, Peterson, Robinson, & Morrison,

2015). Although the DA has field offices, per EO No. 292, they are only authorized to implement laws, policies, plans, rules, and regulations of the department at the regional level. These field offices are then mandated to coordinate with the LGUs who have the authority over the local governance, as provided by the Code (OECD, 2017; Cuevas, et al., 2018).

Since the DA's authority is limited to its regional offices, it cannot direct the devolved agricultural field personnel to undertake the department's projects, programs, and activities without the consent and approval of the LGU. However, LGUs have different sets of priorities; the DA's key result areas do not directly translate to those of the LGUs'. Agriculture, in general, and agricultural extension services, in particular, have to compete with the other key programs of the LGUs (e.g., welfare, health, education, environment, tourism, infrastructure, etc.). Often, local chief executives do not prioritize agricultural programs and activities in their jurisdiction (Ocenar et al., 2004; Cidro, 2015).

Moreover, LGUs also function within a different set of rules from those that govern the DA. One of these rules is the social-structure rule that prevails in Philippine local governance—the *Padrino* system. In LGUs where agriculture is not a priority, projects and programs are impacted by political patronage. For example, local politicians can interfere by altering the intended recipients of certain programs to benefit favored groups. Such cases result in additional project costs, corruption in the system, and inefficiency in operation. These conditions then risk the effective local execution of national programs in agriculture (Magno 2001; Ocenar et al., 2004; Cidro, 2015; Ani & Correa, 2016). “The devolution resulted in the decrease in the DA's control over the actual implementation of national programs in the field level” (Magno 2015, p. 139).

Meanwhile, although the devolution has mandated the agricultural extension services responsibilities to the LGUs, the local officials tasked to implement the programs and projects on-ground are not involved in the planning and policy-making processes. The authority over these agricultural concerns remains with the DA (Magno, 2001; Siamwalla, 2001). The AFMA and the AFMech have reenforced this authority. Yet, these rules do not specify arrangements for the LGUs to have an operational relationship with the DA. Consequently, a situation exists, in which the “national government agencies maintain the power to control, supervise, and review many of the supposed devolved services, even as LGUs are held responsible for them, resulting in confusion, overlaps, and duplication of functions” (Magno, 2015, p. 128). The Code has therefore weakened the extension services institutions in agriculture, impeding their (institutions') ability to perform their functions effectively. There is a gap between national and local implementation of activities, or between the planning and operationalization processes of

agriculture programs. However, the institutional support mechanisms to bridge this gap are lacking.

The successful provision of agricultural extension services highly depends on the coordination and cooperation between the DA and the LGUs. Yet, both the DA and the LGUs operate as two completely separate institutions, and their IEs lack arrangements that would foster a unified collective effort toward the development of local agriculture (Saliot, 2006; Ani & Correa 2016). Thus, the weak link and lack of coordination between the DA and the LGUs have been one of the key challenges for the effective on-ground implementation of agricultural programs (Cidro, 2015; OECD, 2017).

Effects of Institutional Interplays in Agriculture: Financial Resources for Agricultural Extension Services

The lack of funding has been among the primary barriers in implementing the devolved agricultural services (Magno, 2015; Ani & Correa, 2016; OECD, 2017). Along with the functions and services, the devolution has mandated the financial responsibility over local concerns to the LGUs. In line with this, Section 129 of the Code provides the LGUs the power to create their own revenue sources, may these be in the form of local taxes, fees, or other charges. However, in practice, effectiveness of this autonomy is dependent on the character (to rise above the influence of partisan politics, corruption, and rent seeking) of local government leaders and on their ability to generate income for the LGUs (Ocenar, et al., 2004; Cidro, 2015). The Code also provides the LGUs with a share in the proceeds of national taxes in the form of the internal revenue allotment. Title 3 of the Code details the arrangements for this allotment. Specifically, the LGUs' shares from the national coffers amount to 23% for provinces; 23%, cities; 34%, municipalities; and 20% for barangays. These shares are determined through a formula comprising of population (50%), land area (25%) and equal sharing (25%) (Section 285).

In general, majority of LGUs have become dependent on the internal revenue allotment as a fund source. For example, from a 38% contribution of internal revenue allotment to the total LGU income net of borrowings in 1985–1991, this figure rose to 65% in 1992–2003. Specifically, this percentage climbed from 39% (pre-Code) to 81% (post-Code) for provinces; from 38% to 74% for municipalities; and from 33% to 47% for cities. In 1999 alone, LGUs relied on the internal revenue allotment for more than two-thirds of their income (Magno, 2001; Manasan, 2005). However, based on the internal revenue allotment formula, the poor LGUs, which typically have a fewer tax base and less ability to create their own revenue sources, also receive a relatively smaller allocation. As such, poorer LGUs—which are often agriculture-based—have more limited funds to allocate to its numerous devolved responsibilities. Accordingly, LGUs are reluctant to use

funds for agriculture from their own coffers; agriculture competes with the other LGU priorities (Manasan, 2005; Ani & Correa, 2016). Through the years, LGUs have prioritized social services in their budgets; the sector's spending grew by 22% annually, on average, during the 1991–2003 period. The general public services sector spending expanded at a slower pace (16%) during the same period. Still, economic services spending, where agriculture spending belongs, increased the least at 13% (Cidro, 2015). Funds for local agriculture often fall under external sources, securing of which depended on local leadership (Ocenar et al., 2004).

Meanwhile, despite the devolved personnel, the DA central office has maintained most of the funds; in 1997, only 6% of the budget were allocated to the regional offices who were expected to lead the coordination and provision of technical and support tasks under the devolution. The DA do provide funding for national agricultural programs; however, access to it is under the condition that LGUs modify their local plans to suit the national agenda, which sometimes do not match the LGUs' priority goals (Magno, 2001; 2015).

Effects of Institutional Interplays in Agriculture: Human Resources and Agricultural Extension Workers

The enactment of the Code led to the devolution of the DA agricultural personnel—exceeding 17,000 extension workers and administrative staff—to the more than 78 provinces and 1,000 cities and municipalities. This number dwindled to around 12,000 in 2001, and further fell to about 10,000 in 2015 (Librero, 2003; Cidro, 2015; OECD, 2017). Thus, from being the responsibility of the DA, the salaries of these agricultural extension workers (AEWs) has been transferred to the LGUs, and are now governed by the arrangements provided by the Code.

One particular arrangement pertains to the personal services allocation—payments of salaries, wages, and compensations of LGU employees. That is, it should not exceed about 45%–55% of the LGU funds (Section 325 of the Code). This provision poses several difficulties to the LGUs, and they have adjusted (to these challenges) by forming arrangements that later produced cascading problems for LGU personnel.

To illustrate, the personal services spending allocation is generally not sufficient to cover the needs of the LGUs. Hence, LGUs have resorted to the practice of employing personnel on a contractual basis, hired under job orders or service contracts, because these items can be charged against the maintenance and operating expenses (for development projects). This practice has resulted in LGU employees, including extension workers, not having security of tenure and other benefits enjoyed by permanent staff. High employment turnover also followed due to the temporary basis of positions (Ocenar et al., 2004; Manasan, 2005).

The resulting contractual hiring practice of AEWs is also influenced by the *padrino* system or other forms of political influences. First, the municipal or city mayor can appoint an agriculturist in his/her locality as provided by Section 443(b) and Section 454(b) of the Code, respectively. Likewise, due to the nature of the contractual hiring system, the position typically does not undergo the usual government hiring process. Consequently, local chief executives can appoint favored, but not necessarily qualified, people to the job. At times, contracts are not renewed due to the change in administration, and thereby political affiliations, affecting the effectiveness of extension services delivery (Ocenar et al., 2004; Ani & Correa, 2016). The relatively more objective hiring process of the DA has been replaced by a practice highly influenced by partisan politics (Cidro, 2015).

There is also disparity in compensations between AEWs from high- and low-income LGUs since salaries are now based on LGU funds. This situation is aggravated by the position's stagnant salary rates as compared to their counterparts at the national government agencies. In some cases, some experienced demotion in salary when the devolution was initiated. Furthermore, unlike the conditions in the national agency, there is little room for professional development and capacity development in LGUs, resulting in demoralized, unmotivated, and low-morale AEWs. These employment conditions exist in most areas, especially in the economically challenged LGUs (Cidro & Radhakrishna, 2003; Librero, 2003; Cidro, 2015; Ani & Correa, 2016).

Interplays among National and Local Institutions in Climate Change Adaptation: Mainstreaming of Climate Change Adaptation

The Act is a vital component of the IE for CCA. Section 4 of the Act created the Climate Change Commission to be the primary authority in coordinating, monitoring, and evaluating government programs and action plans on climate change. The Climate Change Commission is an independent and autonomous body, with the same status as that of a national government agency. As a national agency, the Climate Change Commission has its own sets of key result areas. However, Section 2 of the Act "declared the policy of the State to systematically integrate the concept of climate change in various phases of policy formulation, development plans, poverty reduction strategies and other development tools and techniques by all agencies and instrumentalities of the government". As such, all agencies in the government, including the DA, have their own programs on climate change in line with their respective key result areas. The development of key result areas is typically independent from one agency to another; thus, even with a common CCA agenda, the programs, projects, tasks, and efforts of varying government agencies are typically not in synergy. Consequently, organizational cohesion is lacking among government agencies concerning climate

change, especially at the national scale (Cuevas et al., 2015).

The lack of organizational cohesion is manifested in the unclear delineation of roles and responsibilities among institutions on the issue of CCA (Dator-Bercilla, Roxas, Holtsberg, & Inagaki, 2012; Cuevas et al., 2014). This situation is often accompanied with the absence of organizational cooperation and collaboration arrangements for effective planning. To illustrate, with the implementation of the Act, the Philippines developed its National Climate Change Action Plan. The plan outlines the agenda and priority strategies of the government for CCA (CCC 2010). However, the National Climate Change Adaptation Plan, which was designed by the Climate Change Commission, and the Philippine Development Plan 2011–2016, which was developed by another, were not fully aligned in what they regarded to constitute "adaptation". As the plans at the highest policy level, their lack of alignment can possibly result in discrepancies among departmental and local development plans, and programs, activities, and projects (OECD, 2017).

The lack of organizational cohesion likewise risks the occurrence of overlapping interactions among institutions, which may result in duplicate or inconsistent CCA efforts. This is observed between the Climate Change Commission and the National Disaster Risk Reduction and Management Council, in which the two agencies are not coordinated vis-à-vis DRR and adaptation concerns (OECD, 2017). Similarly, the DA launched the Climate Change Systems-Wide Program as an effort to mainstream climate change into the country's agriculture and fisheries modernization programs (Department of Agriculture, 2018). The lack of organizational cohesion is again evident as:

... DA's Climate Change Systems-Wide Program does not make explicit reference to National Climate Change Adaptation Plan strategic priorities... it is unclear how different institutions at the national, sectoral and local levels co-ordinate in the design and implementation of existing and future climate programs, activities, and projects... In addition, overlaps and co-ordination issues may arise among different institutions in the implementation of programmes... (OECD 2017, p. 185).

At the local scale, the government field offices are unfamiliar with the function of their institution in local CCA-DRR activities, implying a lack of organizational cohesion. The field offices abide by their respective institution's key result areas and mandated functions. These key result areas are usually not coordinated with one another; thus, field offices are unable to partake in local CCA-DRR initiatives effectively (Cuevas et al., 2015).

As mentioned earlier, the authority of government agencies, like the DA, is restricted to the regional offices. The national government agency, which has a direct influence on local affairs, is the Department of Interior and Local Government by virtue of RA 6975 of 1990. In performing its mandate, the department establishes and prescribes rules, regulations, and issuances regarding laws affecting LGUs. The interior department also lays down plans, policies, programs and projects that promote and support the administrative, technical, and fiscal capabilities of local government offices and personnel.

According to Section 15(b) of the Act, the department is also tasked to “facilitate the development and provision of a training program for LGUs in climate change”. Hence, the various department memorandum circulars prescribe guidelines in some areas of local CCA mainstreaming (Table 3). However, even with the Department of Interior and Local Government’s efforts, there is still a gap on how to translate national CCA measures to local environments. This gap exacerbates the unclear delineation of responsibilities of the institutions in relation to CCA. Accordingly, this results in conflicts “between national and local governments over the functions and the definition of the LGUs role in the implementation of adaptation programs and projects” (OECD, 2017, p. 183).

Such conditions are due to the lack of institutional arrangements that support the emergence of climate change and CCA prioritization within the government. As mentioned earlier, the Code does not provide for processes or procedures to help LGUs to develop an operational relationship with the DA. Similarly, such arrangements are likewise not provided in the Act; thus, a gap between the national and local operationalization of CCA exists due to the counterproductive interplays that arise between the Code and the Act.

The lack of institutional support mechanisms is also most evident in the lack of guidance for mainstreaming CCA into local endeavors. LGUs are mandated to produce the Local Climate Change Adaptation Plan upon the enactment of the Act in 2009. However, the guidelines to support the mainstreaming efforts, such as the memorandum circulars of the Department of Interior and Local Government, specifically, the “Guidelines on the Formulation of Local Climate Change Action Plan” and “Guidelines on Mainstreaming Climate Change Adaptation and Disaster Risk Reduction in Local Development Planning”, were provided only in 2014 and 2015, respectively. Likewise, the *LGU Guidebook on the Formulation of Local Climate Change Action Plan* was released in 2014, while the *Supplemental Guidelines on Mainstreaming Climate and Disaster Risks in the Comprehensive Land Use Plan* was made available in 2015. During the years in between, LGUs found it difficult to comply with the Act and were uncertain on how to accomplish their responsibilities as mandated by the legislation. Moreover, LGUs are burdened with

the multiple requirements, particularly the approximate 30 sectoral plans, assigned by other laws and policies. These overlapping responsibilities hamper LGUs from focusing on mainstreaming CCA into local plans (Cuevas et al., 2016).

Meanwhile, as provided by the Code, local activities are under the control of the LGUs. Like agriculture, incorporating CCA into the local priorities depends on the LGUs’ needs and/or on the level of cooperation between the LGU and the central government (OECD 2017). Thus, this highlights the significance of local leadership support to the CCA endeavor. In the Philippines, local leadership has proved to be an effective catalyst for local CCA, in the form of a climate change champion. The champion is most influential if s/he is the local chief executive because the Code includes provisions that enable LGUs to create and execute their own decisions within their jurisdictions. Specifically, the local chief executive has the executive and legislative authority to promote and act on concerns s/he considers significant to the general welfare of the LGUs. Thus, as a climate change champion, s/he can advance local CCA implementation, such is the case in the province of Albay (Cuevas, Peterson, & Morrison, 2015; Cuevas, Peterson, Robinson, et al., 2016).

To illustrate, the Governor of Albay during the period 2007–2016 was able to institutionalize a number of endeavors to address climate change. Through the Provincial Executive Order 2007-12-A, the Center for Initiatives and Research for Climate Adaptation (CIRCA) was established in the province as a key institution on climate change. Furthermore, CCA was prioritized in the province by virtue of the Provincial Resolutions 2007-04 and 2007-24. The Provincial Council Resolution 2008-44 also encouraged the Provincial Government of Albay-CIRCA, the DA, the Department of Environment and Natural Resources, and the Department of Agrarian Reform to conduct training and workshops in order to incorporate climate change into local land use plans. Most importantly, the Provincial Government of Albay spearheaded the First National Conferences on Climate Change Adaptation, an output of which was the call for an early passage of the Act. Through these efforts, local leadership influenced the local government to prioritize CCA, encouraged the LGU to commit to CCA, and influence the mindset of the community toward CCA. The governor, as a climate change champion, represented a social-structure institution that was able to influence individual acts and expectations into a collective action, convert personal beliefs into social norms, and command collective behaviors (Cuevas, Peterson, & Morrison, 2015; Cuevas, Peterson, Robinson, et al., 2016). In this case, the Code complements the Act and other formal rules on CCA.

Effects of Institutional Interplays in Climate Change Adaptation: Finance and Human Resources

Given that the local governance IE is primarily governed by the Code, it is likely that the issues encountered in the agriculture extension services IE are experienced in the local CCA IE. LGU involvement is further reinforced by Section 14 of the Act, which provides for the LGUs to be the frontline agencies in formulating, planning, and implementing climate change action plans in their respective jurisdictions.

Section 18 of the Act authorizes the LGUs to utilize portions of their internal revenue allotment to CCA-related activities. However, as presented earlier, LGU funds are not sufficient to cover the already-existing LGU responsibilities. Hence, there is little room for CCA programs from these funds. The amendment of the Act—Republic Act (RA) 10174 of 2011 that created the People's Survival Fund—intends to address this financial concern. The People's Survival Fund is a special fund in the national treasury aimed to finance local adaptation programs and projects. However, it took years after the enactment of the People's Survival Fund for the implementing rules and regulations of the policy to come out (through the Climate Change Commission Resolution No. 3 dated 13 November 2015). Thus, during the intervening years, LGUs were unable to access the fund; but LGUs were already required to implement the Act.

When the implementing rules and regulations of the People's Survival Fund were released, LGUs began submitting funding proposals. However, it soon became evident that there were gaps in the process to access the funds in terms of technical requirements of the proposals. As of mid-2017, there were only two proposals approved; most were approved in concept, awaiting submissions of more technical particulars, or were returned to LGUs for revisions (Supnet, 2017). The People's Survival Fund Secretariat and the Climate Change Commission assisted in making the People's Survival Fund more accessible by publishing the *Proponent's Handbook: A Guide on How to Access the People's Survival Fund* in 2016 and *Accessing the People's Survival Fund Training Manual* in 2017. Nonetheless, these were made available years after RA 10174 had been enacted; thus, the impacts of these efforts are yet to be realized as of this writing. Essentially, the funds for CCA activities were made available to the LGUs; however, the institutional support mechanisms to ensure that the available funds can be accessed by the intended beneficiaries are lacking, thereby creating barriers to local adaptation (Cuevas et al., 2015).

In 2010, the Philippines passed the Philippine Disaster Risk Reduction and Management Act, which institutionalized the synergy of climate change and DRRM in the government agenda. The law's implementing

rules and regulations specified the creation of the local disaster risk reduction and management (LDRRM) officer. Although the officer's primary responsibilities are on DRRM concerns, s/he is also tasked to collect information on natural hazards, local vulnerabilities, and climate change risks, and to maintain local climate risk maps (Rule 6, Section 4 of Implementing Rules and Regulations). Meanwhile, as per Department of Budget and Management Memorandum dated March 15, 2012, "the personal services requirement of position created for an LDRRM Office shall be funded from LGU funds and is subject to the personal services limitation of LGU budgets." Thus, as in the case of agriculture, the creation of the LDRRM officer's position is ruled by the limitations and constraints of the Code. Hiring permanent personnel is already difficult for LGUs as most have already reached their respective budgetary ceilings. This then translates to unavailable budget for a new LGU position. However, LGUs are mandated to comply with the law despite the prevailing difficulties surrounding local personnel.

LGUs operate without the sufficient financial resources to create a permanent position for the LDRRM officer. Thus, LGUs have resorted to designating the position, or its responsibilities, to existing regular LGU personnel. The designated LDRRM officers end up overworked, underpaid, and unmotivated; aside from the responsibilities they were originally hired for, they have been burdened with significant tasks on CCA and DRRM concerns without additional compensation, financial or otherwise (Cuevas et al., 2015). Like in the case of agriculture, hiring of LDRRM officers on a contractual basis became the norm in some LGUs in order to address the unavailable permanent local position. This again has resulted in LGU employees with no security of tenure, and without the benefits experienced by permanent personnel. Similarly, LGUs also rely on funding the LDRRM officer's salary from the development project funds. These efforts resulted in temporary employment of officers and high LGU staff turnovers. This employment problem is critical in CCA-DRRM because it disrupts the continuity in the management of CCA-DRRM work and causes low or no return on investments for CCA-DRRM training and education (of LDRRM officers) (Cuevas et al., 2016; Cuevas, 2018).

Since local CCA also operates within the local governance IE, the *padrino* system is also at work, in which the officers are appointed based on political considerations rather than on merit. Political appointments typically end with less qualified LDRRM officers in terms of knowledge, experience, and appreciation of climate change and/or DRRM concerns. Additional problems arise with the *padrino* system influencing local hiring.

As a political appointee, the LDRMM officer is co-terminus with the mayor. Thus, a change in local political power signifies losses in human resource investments, which in this case is the

CCA-DRR trained LDRRM officer (Cuevas et al., 2016, p. 2053).

Based on the discussions above, it is clear that the same issues and concerns that affect the local agriculture also affect local CCA because both operate within the local governance IE. As such, local agricultural CCA works within three IEs—agriculture, CCA, and local governance.

Conclusions

This article advocates that analyzing the institutional environment where CCA endeavors will be implemented can make policy and decision makers and planners better understand and have deeper perception of the interlinkages between and among institutional arrangements. It aims to show that for CCA policies, plans, and programs to be effectively implemented at the local level, it is necessary to understand the institutional environment where CCA initiatives are to be implemented. Further, the paper intends to demonstrate that, along with the scientific and technological discussions, institutional conversations should be among the initial vital steps in CCA planning. Lastly, the institutional dimension should be the foundation of broader reforms toward an effective CCA implementation.

This institutional analysis, through examining the institutional environments, has resulted in the following findings:

- Local agricultural CCA works within three IEs—agriculture, CCA, and local governance. Formal rules (e.g., AFMA, AFMech, EO No. 116, the Act, among etc.), govern primarily the IEs of agriculture and CCA at the national scale. However, both the formal rules and social structures (i.e., culture, norms, practices) have significant influence on the local governance IE.
- Local governance institutions and arrangements have vital roles and influences in the operationalization of local agricultural CCA. Both the LGU and the Code have the most links to other institutions in agriculture and CCA IEs.
- Agriculture in the Philippines was decentralized via the Local Government Code of 1991. The Code provides LGUs with extensive authority over their jurisdictions and autonomy in governance. The enactment of the Code is counterproductive with the mandates of the other institutions in the agricultural IE because the Code lacks the arrangements that can facilitate one of the vital functions of institutions (as per IEM framework): to create (dis)incentives for individual and collective actions (i.e., rewards and penalties; payoffs on actions). This situation helps to create

the existing personality-driven style of local governance in the Philippines; a style which encourages coordination arrangements among actors to be founded on personal relationships (i.e., *padrino* system) rather than institutional. The *padrino* system exhibits counterproductive interplays with other institutions in the agriculture IE, and later in the CCA IE. It has often (than not) affected the: 1) priorities of the LGUs; 2) implementation of national programs in the LGUs; and 3) selection of LGU personnel.

- On the other hand, the personality-driven style of local governance enables local CCA to be implemented effectively when a climate change champion exists, particularly when this champion is the local chief executive. The provisions in the Code affords a climate change champion to influence local legislation, initiate programs, and support implementation of national initiatives at the local scale; these provisions complement the other institutional rules on CCA. With the local chief executive as a champion for either agriculture or CCA or both, s/he can function as the institution that connects individuals to society toward the agenda. In this case, the Code establishes a system of power and authority that complements the Act although it is under a conditional setting—with the existence of a climate change champion.
- The Code is likewise counterproductive with other pieces of legislation in terms of funding. The burden of financing all local programs, projects, and activities are borne by the LGUs. Although the Code enables LGUs to have financial autonomy in practice, the ability of LGUs to acquire financial resources outside the national funds (i.e., internal revenue allotment) still depends on the personality and ability of the local chief executive.
- The successful provision of agricultural extension services highly depends on the coordination and cooperation between the DA and the LGUs. Yet, both entities operate as two completely separate institutions, and their IEs lack arrangements that would foster a unified collective effort toward the development of local agriculture. Similarly, CCA actors lack organizational cohesion, thereby compromising how they operate within the CCA context. This lack of cohesion typically manifests in the unclear delineation of roles and responsibilities among institutions regarding CCA issues. These conditions in agriculture and CCA highlight a significant function of institutions—reducing uncertainties. In particular, the institutional function of providing structure in procedures and processes (i.e., setting rules or agreements that preside over the how activities

are implemented) is lacking; hence, institutional support mechanisms that are necessary to bridge the gaps between and among institutions are wanting.

- The lack of institutional support mechanisms is most evident in the lack of guidance for mainstreaming CCA into local endeavors. LGUs are mandated by the Act to implement local CCA, but the guidelines and directives to support the mainstreaming efforts are wanting.

These findings suggest that the Code needs to be revisited and amended to address the concerns at the local level. For one, the Code already has existing counterproductive interplays with other institutions. For another, the Code does not have the needed arrangements for addressing a new phenomenon like climate change. Following the functions of institutions in the IEM framework, the amendments should include establishing arrangements that create (dis)incentives for individual and collective actions (i.e., rewards and penalties; payoffs on actions) promoting local agriculture and CCA in order to minimize the influence of personality-driven type of local governance. With these institutional arrangements, the existence of a local chief executive that champions these causes (agriculture and CCA) may no longer be needed as a condition for the personality-driven style of local governance to have positive effects.

Arrangements that improve the financial capacities of LGUs, especially in relation to human resources, should also be incorporated in the Code. The current personal services allocation in the Code is not working effectively to address the needs of the LGUs. Likewise, arrangements that provide better structure in procedures and processes are needed to address concerns on political appointments and human resources. Lastly, the Code needs to be updated and amended to include arrangements pertaining to climate change and CCA.

Meanwhile, the analysis of the CCA IE implies that new institutions (i.e., laws, policies, regulations) need institutional support mechanisms that are not reactive (those responding to issues already existing); these mechanisms should be anticipatory (those that are planned or prepared in advance before issues arise). For example, the People's Survival Fund could have been better implemented if the guidelines on how to access the fund were available upon the enactment of the law. Similarly, mainstreaming of CCA into local plans may have been less of a burden to LGUs if institutional arrangements (i.e., sets of rules or agreements) that preside over how local mainstreaming activities are to be implemented were provided in a timely manner. These institutional arrangements include the guidelines and guidance books on local mainstreaming. Thus, institutional support mechanisms should be designed simultaneous with the development of new laws and policies. Under current circumstances, anticipatory

institutional support mechanisms may no longer be possible; however, it needs to be noted that the arrangements to improve the current conditions should be based on the analysis of institutional environments and institutional interplays.

The results show that institutional analysis is not given its warranted attention in CCA efforts in the Philippines. This article presented the significance of institutional analysis and provided a concrete example on how to conduct it in the CCA discussion. It demonstrated the complexity of institutional linkages and illustrated that institutional analysis should be among the initial steps in CCA planning. There are still a wide range of issues affecting both agriculture and CCA at the local scale, such as capacity development, technology transfer, and research and development. These concerns involve other sets of institutions and arrangements, thereby creating various arrays of institutional interplays. Future research can look into these issues under institutional lens to further establish that the institutional dimension should be the foundation for reforms toward the effective CCA implementation.

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Climate Change, Impacts and Adaptation Strategies of Farmers in Roxas Mountain Range, City of Koronadal, Philippines

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Abstract

Farmers in the Roxas mountain range, City of Koronadal used to have bountiful harvests during the time when the city was still free from climate-related hazards. However, this situation has recently changed due to the increasing climate-related risk events. Moreover, localized baseline scientific climate information is limited to foster the development of appropriate adaptations and policies toward climate-resilient communities. This study assessed the climate trends and the changes, impacts, and adaptation strategies of farm households in five barangays in the Roxas mountain range, Koronadal City, South Cotabato. The study conducted household surveys with 265 respondents, focus group discussions, and key informant interviews. In using Mann-Kendall test statistics, time series analysis and one-way analysis of variance, the findings from 1981 to 2012 show increasing trends with significant changes ($p < 0.01$) in mean minimum temperature, increasing by 0.74°C for three decades. In contrast, mean maximum temperature showed a decreasing trend with an average decrease of 0.65°C , $p < 0.01$). In three decadal periods, an average increase of 0.04°C in monthly mean temperature was observed. Rainfall patterns during the same period also show significant changes in the months of June ($p < 0.01$), August, and December ($p < 0.05$); these findings suggest that climate change occurred. Floods, landslides, and droughts were experienced by the communities, which had devastating socioeconomic and environmental impacts. The existing adaptation strategies are just stop-gap solutions that address the effects of climate change but do not consider the root causes. To consider future changes in climate patterns, the socioeconomic and political structure and processes of the communities need to change; this can be achieved if multifaceted drivers of climate change hazards and their impacts are appropriately and immediately addressed. Some grassroot-level transformative adaptation strategies identified in the study consist of socioeconomic facets, specifically, *investment in children's education, financial management, family planning, and development of alternative on-farm and nonfarm livelihood options*. The environmental aspect, which includes *promoting agroforestry system, water impoundment technologies, and advanced early warning system*, were also considered.

Keywords: climate trends, variability, climate change, climate impacts, transformative adaptation

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Highlights

- The monthly and yearly temperature and rainfall patterns from 1981 to 2012 significantly changed, which suggest that climate change occurred in Roxas Mountain Range, City of Koronadal.
- The manifestations of climate change observed and experienced by the local farmers include intense heat and rainfall, floods/flashflood, landslides, and drought. These manifestations have adverse social (e.g., migration, decreased working time at the farm, loss of lives and properties), economic (declined crop yields, increased occurrences of pests and diseases, delays in planting) and environmental impacts (reduction of water supply and loss of landscapes aesthetic value) to the local farmers.
- The local government plays a crucial role in facilitating and promoting appropriate adaptation strategies against climate change. These strategies have increased the local communities' awareness of climate change and have transformed the socioeconomic, environmental, and political structures and processes in the communities. Some of the potential transformative socioeconomic adaptation strategies identified are *investment in education* through scholarship programs and the *support provided for alternative on-farm and nonfarm livelihoods*. In addition, *promoting agroforestry system* or diversified farming has enhanced the aesthetic landscape and has served as the best adaptation and mitigation option to climate change.

Introduction

The City of Koronadal has been declared several times under a state of calamity due to incidents of flash floods and landslides, such as those that occurred in July 2013 and in June 2015 (Philippines News Agency [PNA] 2015). In 2016, the city was yet again placed under a state of calamity twice due to the severe drought in March (CNN Philippines, 2016) and to the flooding in October (Canlas, 2016).

The communities commonly experience intense heat and heavy rainfall. In 2020, the *Philippine News Agency* (PNA) reported that the City of Koronadal experienced episodes of flooding and landslide, which affected more than 200 families in several villages. These hazards were caused by a two-hour heavy rains, which then caused the Bulk Creek to overflow after a large volume of water from upland villages flooded into the creek (Estabillo, 2020). These climate risk events have consequently affected properties, facilities, infrastructures, and the people and their livelihood sources that are highly dependent on the weather (i.e., agricultural production). It is unclear, however, if such climate risk events experienced by the affected

farmers in the City of Koronadal are related to climate change and climate variability.

According to the Intergovernmental Panel on Climate Change (IPCC), *climate change* is a change in the state of a climate, which can be identified through the changes in the mean and/or the variability of its properties that persist for an extended period, typically decades or longer. Meanwhile, *climate variability* is defined as the variation in the mean state and other statistics (e.g., standard deviations) and the occurrence of climate extremes on all spatial and temporal scales beyond that of individual weather events (IPCC, 2013b). The increasing mean temperature; significant variation in precipitation patterns; rising sea level; and increasing frequency and growing intensity of extreme weather events (e.g., drought, floods, and landslides) are the manifestations of the changing climate and variability (Asian Development Bank, 2009). Consequently, these manifestations have adversely affected the agriculture sector—a sector that highly depends on the weather (Gentle & Maraseni, 2012)—and the people living in rural areas who have limited adaptive capacity (International Fund for Agricultural Development, 2009).

In view of these, climate change adaptation is needed in order to cope effectively with the impacts. Moreover, adaptation strategies must be considered as an integral part of a holistic response to building the capacity and resilience of communities such that they can withstand the range of shocks and stresses (CARE International, 2009; IPCC, 2007). Hence, transformative adaptation strategies are needed (Tabara, Jager, Mangalagiu, & Grasso, 2018). *Transformational adaptation* changes the fundamental attributes of a system in response to climate and to its effects (IPCC, 2014). It requires local leadership and the efforts of various actors in implementing transformative adaptation (Kates, Travis, & Wilbanks, 2012).

The United States National Research Council (2010) cited that understanding climate change and its evidence is vital for decision makers such that they can respond effectively to its various causes and impacts. Accordingly, assessing the impacts of climate change on smallholder farmers and identifying the appropriate adaptation strategies need to be done as the information on these aspects at the grassroots level are very limited (Harvey et al., 2014). In addition, localized evidence-based information on climate-related trends and changes in Koronadal City is still limited and not well established. This set of information could serve as scientific baseline information for local government units (LGUs) when crafting policies that would reduce the adverse impacts of climate change. Specifically, these policies could focus on either enhancing the existing conditions or developing appropriate adaptation measures.

In this context, this study aimed to:

1. Examine the climate trends and changes in

- temperature and rainfall patterns, and the communities' perception of climate change in the study area;
2. Determine the impacts of climate change to farming livelihoods; and
 3. Examine the current and potential transformative adaptation strategies in response to climate change impacts.

Methodology

Location of the study

The study was conducted in five farming *barangays* (districts) (i.e., Assumption, Saravia, Carpenter Hill, Paraiso, and San Isidro) in the Roxas mountain range in Koronadal City, South Cotabato province (Figure 1). The Roxas mountain range was selected as the study site because it is vulnerable to climate-related hazards that affect farming livelihood sources. Based on the 2010 report of the Mines and Geosciences Bureau–Region 12, two out of the eight barangays within the Roxas mountain range are highly susceptible to landslides (i.e., Barangay Assumption and Barangay Saravia), while three are moderately susceptible

(i.e., Barangay Carpenter Hill, Barangay Paraiso, and Barangay Sta. Cruz). However, the localized scientific baseline information on the impacts of and adaptation measures on climate-related risks in these areas are still limited. Accordingly, these are important components to reinforce the adaptation planning in the locality.

The residents within the Roxas mountain range have farming as their means of livelihood. The area provides food and other important natural resources (e.g., water, forest and non-forest products) to these communities and nearby barangays. Majority of the households cultivate corn, rice, root crops, vegetables, and other high-value commodities (e.g., banana and coconut, in farmlands with areas of from 0.5–4.0 ha.

The Roxas mountain range was decreed as a watershed area by of virtue Proclamation No. 607 and has a total land area of 1,137 ha. As a watershed with full vegetation, it should be that the area is capable of holding water and preventing erosion, landslides, and flashflood. However, the flood events in Koronadal City are usually caused by the large volumes of water coming from the upland villages (Estabillo, 2020), such as those from the Roxas mountain range.

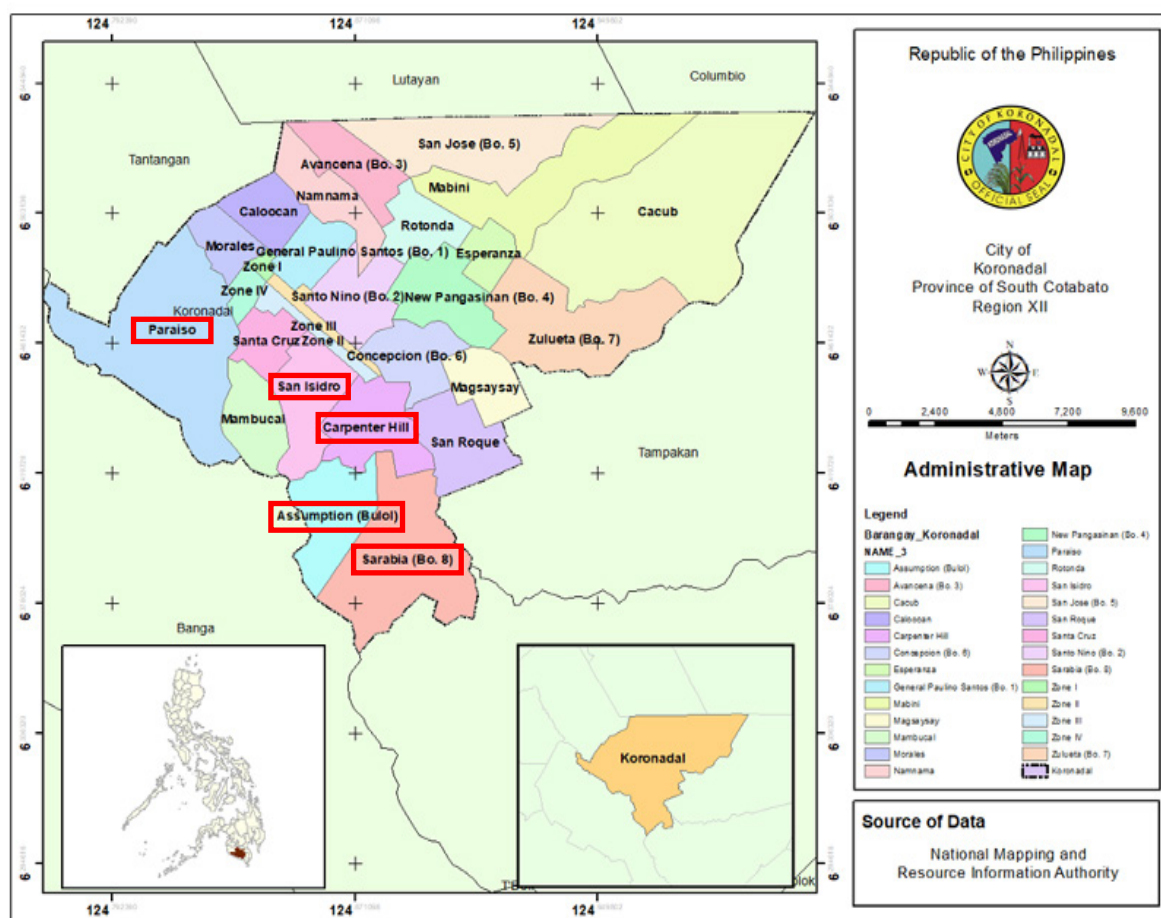


Figure 1. Administrative map of Koronadal City, South Cotabato

Notes: The study sites are boxed in red.

The landscape of the Roxas mountain range is one of the distinct physiographic features of the City of Koronadal which is a land-locked area situated in Southern Mindanao. It is composed of 27 barangays and has a total land area of 277 km² (City Development Planning Office, 2009). It is also home to some of the B'laan indigenous people. The climate in the study area belongs to the fourth type under the Corona Climate System Classification, which is characterized as mild and subtropical with June to October as the rainy months. The City of Koronadal used to be typhoon-free, albeit this has changed over time.

Data Collection

A courtesy visit to the city government of Koronadal City was conducted, and subsequently secured a study permit to conduct data collection in the five barangays. Household survey, focus group discussion (FGD), and key informant interviews (KII) were then conducted from April 2013 to July 2015.

A total of 265 randomly selected farm households served as survey respondents. The number of respondents was determined using the formula of Sukhatme (1953) (Equation 1). Stratified random sampling using lottery technique and proportional allocation were also done to determine the sample size per barangay (Table 1). Majority (59%) of the respondents in the household survey have been living in the community for more than 30 years, and their ages ranged from 20 to 84 years old. About 59% were female, while the rest were male.

$$n = \frac{N \cdot P}{P \cdot CV^2 (N-1) + Q} = \frac{5,830 \cdot 0.05}{0.50 \cdot 0.06^2 (5,830-1) + 0.50}$$

where:

- n = sample size
- N = household population (5,830)
- CV = coefficient of variation (set to 0.06)
- P = proportion of households who are vulnerable (set to 0.5)
- Q = $1 - P$
- n = 265 households (sample size)

Secondary data, such as the observed climate data from 1981 to 2012, were taken from the station of the Philippine Atmospheric, Geophysical, and Astronomical Services Administration (PAGASA)-General Santos 55 and from the PAGASA central office since there was no available historical climate data in the study area. Meanwhile, the potential adaptation plans were identified through the household survey and FGD; these strategies were developed based on the 2011 PAGASA

climate projection downscaled scenarios in Region 12. Baseline maps and sociodemographic profiles were also gathered from the LGUs.

Table 1. Proportionate distribution of the respondents within the study area

Barangay	Sample Size
1. Assumption	17
2. Saravia	64
3. Carpenter Hill	58
4. Paraiso	52
5. San Isidro	74
Total sample size	265

Data analysis

The data gathered were analyzed qualitatively and quantitatively. The climate data were subjected to trend and change analysis using time series analysis. Specifically, five-year moving averages and simple linear regression were used to analyze the climate trends. The five-year moving average was calculated by getting the average every five years within the 31 year climate data. The nonparametric Mann-Kendall test statistics were also performed to test the presence of monotonic increasing or decreasing trend in the time series data. A simple linear regression was used to show the long-term annual trends in temperature (minimum, maximum, and mean) and rainfall data from 1981 to 2012. Subsequently, the coefficient of determination (r^2) was computed.

The entire time series data were divided into three decadal periods to determine the changes in rainfall and temperature patterns. The changes in climatic patterns were analyzed in two ways. First through running a monthly analysis of the three time periods using the F-test through a one-way analysis of variance (ANOVA), whereas the second method is through performing a yearly decadal analysis of the three time periods using the T-test and one-way analysis. These were employed to do a pairwise comparison of the three decadal periods. The analysis was divided into three periods: Period 1: 1981–1990, Period 2: 1991–2000, and Period 3: 2001–2010.

On the other hand, the data on the communities' perceptions of the observed changes in climatic conditions and its causes, which were gathered from the household survey, were analyzed. The identified impacts of and adaptation to climate variability and

change were also analyzed using descriptive analysis. The 2011 PAGASA downscaled climate scenario (medium range) of South Cotabato was used to identify the potential transformative adaptation options that could be used by the affected communities. The trend and change scenarios for 2020 and 2050 were explained during the household survey, and this became the basis for identifying the potential transformative adaptation strategies.

Results and Discussion

Observed climate trends, climate change and community perception

Observed trends

The results of the regression analysis and Mann-Kendall test statistics of the annual mean minimum temperature ($t_{\min}$) from 1981 to 2012 show a significant increasing trend (Figure 2) at a rate of 0.0266 ± 0.0061 . In 1987 and 2002, $t_{\min}$ drastically increased by 0.61°C and 1.39°C , respectively; and a drop was detected in 1983 and 1985. In contrast, the annual mean maximum temperature ($t_{\max}$) exhibited a statistically significant decreasing trend (Figure 3) at a rate of -0.0340 ± 0.0101 . In 1988, $t_{\max}$ spiked by 0.85°C and then dropped by 1.35°C and 1.28°C in 1999 and 2011, respectively. The significant increasing trend in $t_{\min}$ and decreasing trend $t_{\max}$ implies episodes of *El Niño* and *La Niña*, respectively.

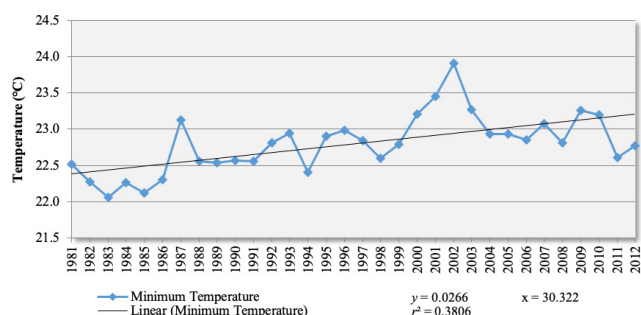


Figure 2. Observed trends of annual mean minimum temperature in 1981–2012

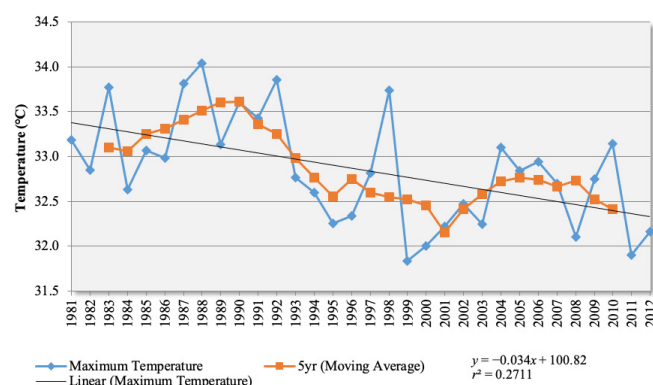


Figure 3. Observed trends of mean annual maximum temperature in 1981–2012

The daily minimum temperatures are projected to increase faster than the daily maximum temperatures. This will consequently decrease the diurnal temperature range and increase the likelihood that extreme weather events (e.g., droughts, landslides, and flooding) would occur (Meehl et al., 2007).

Droughts were observed in 1987 and 2002 in the Philippines (Hilario, Guzman, & Ortega, 2009; Climate Change Prediction Center-National Oceanic and Atmospheric Administration, 2015). Accordingly, a warming trend in minimum temperature can significantly affect crop yields, which then calls for the development of suitable adaptation strategies to sustain production (Rao, Chowdary, Sandeep, Rao, & Venkateswarlu, 2014). For every 1°C increase in minimum temperature, rice yield could decline by as much as 10% (Laborte et al., 2012).

The observed $t_{\min}$ and $t_{\max}$ trends in the study area are different from the observed current climate trends in the country. According to Cinco, Hilario, De Guzman, Emma, and Ares (2013), $t_{\max}$ and $t_{\min}$ trends from 1951 to 2009 were increasing by 0.36°C and 1.0°C , respectively; the same goes for the annual mean temperature. Such differences in the observed results may be due to the scope of measurement since all areas of the country had been covered by Cinco et al. (2013), which was wider in range and hence, more varied.

The results of the linear regression and the five-year moving average (Figure 4) as well as the Mann-Kendall test statistics of observed annual mean temperature also show a decreasing, although not significant, trend at a rate of -0.0037 ± 0.0059 . Mean temperature dropped in 1984, 1999, and 2011 by 0.41 , 0.54 , and 0.60 , respectively. Moderate-to-strong *La Niña* events also occurred in the years mentioned. Meanwhile, the total annual rainfall (Figure 5) shows an increasing trend, albeit the increase is not significant. There are years, however, when rainfall decreased. For instance, the annual mean rainfall in 1991 and 1992 decreased by 200 mm and 143 mm, respectively. On the other hand, the highest annual rainfall is about $1,346.4$ mm in 1999, which coincided with episodes of *La Niña*.

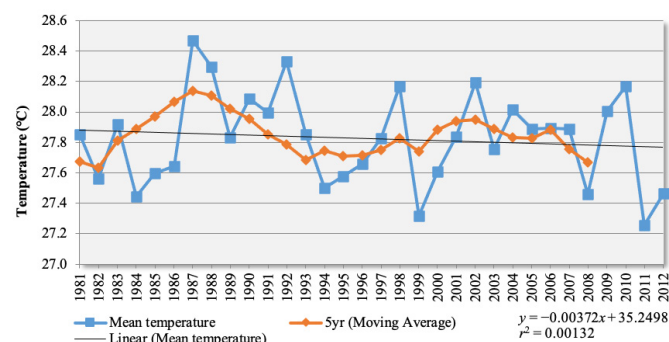


Figure 4. Observed trends of annual mean temperature in 1981–2012

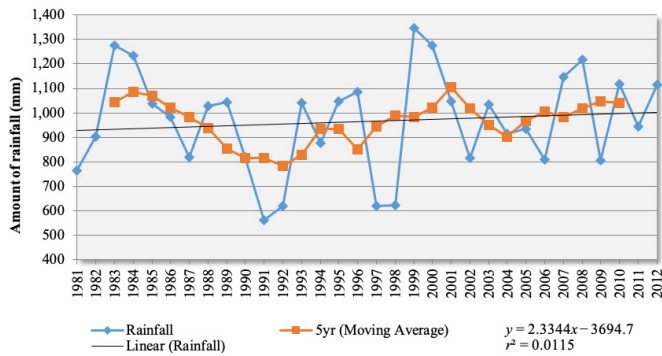


Figure 5. Observed trends of annual total rainfall in 1981–2012

Observed climate change

Monthly analysis of observed changes in annual t_{min} from 1981 to 2012. The monthly analysis of the three decadal periods indicates a statistically significant change from January to December ($p < 0.01$). The annual t_{min} significantly changed from 1981 to 2012, particularly the annual t_{min} in the summer months from March to May. The annual t_{min} during the month of March in period 1 is 22.5 °C. In the months of April to May, the decadal increase in temperature in periods 2 and 3 are 0.2 °C and 0.8 °C, respectively. This implies that the annual t_{min} in all months, except January, exhibit changes during the three decadal periods (Figure 6).

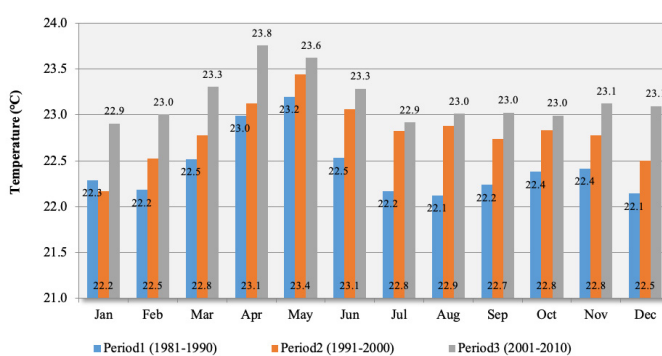


Figure 6. Monthly mean annual minimum temperature

Monthly analysis of observed changes in annual t_{max} from 1981 to 2012. The monthly analysis of the three decadal periods for annual t_{max} also reveals statistically significant changes from January to December ($p < 0.01$), except for the months of June and September. Similarly, changes in the monthly annual t_{max} for the three decadal periods can be noticed (Figure 7).

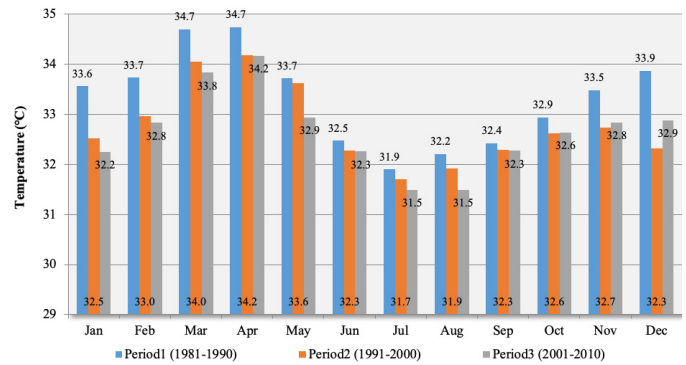


Figure 7. Monthly mean annual maximum temperature

Monthly analysis of observed changes in annual mean temperature from 1981 to 2012. Similarly, the monthly analysis of mean annual temperatures reveal statistically significant changes ($p < 0.01$) for January, April to September, and December (Figure 8).

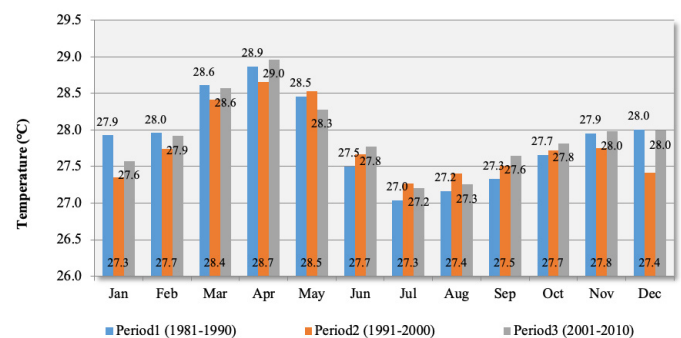


Figure 8. Monthly annual mean temperature

Monthly analysis of observed changes in total annual rainfall from 1981 to 2012. The monthly total rainfall for the three periods show statistically significant changes in June ($p < 0.01$), August and December ($p < 0.05$). No significant changes can be observed in the other nine months. Figure 9 shows the trend in monthly total annual rainfall for periods 1, 2, and 3. The month of June exhibits a very drastic drop in annual rainfall in periods 1 and 2.

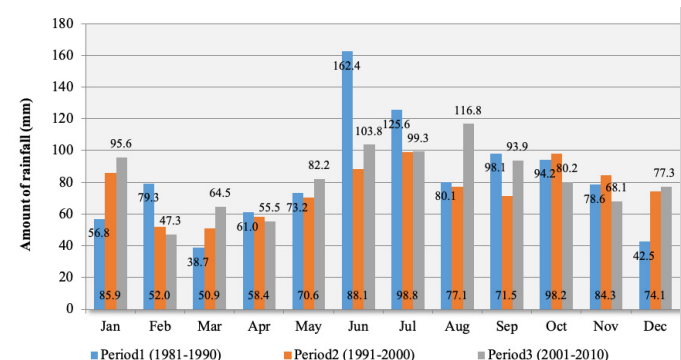


Figure 9. Monthly total rainfall

Yearly decadal analysis of observed changes in climate parameters, 1981–2010

The maximum, minimum, and mean annual temperatures significantly changed ($p < 0.01$) throughout the three time periods; there was no significant change in the rainfall parameter. Meanwhile, the results of the t-test that compare the changes in climate parameters in the different periods show that the minimum temperature at all periods significantly changed ($p < 0.01$). Specifically, the maximum temperature in periods 1 and 2 and periods 1 and 3 significantly changed at 1% level of significance. Periods 2 and 3 also indicate significant changes, albeit at a 5% level of significance. On the other hand, the annual mean temperature significantly changed ($p < 0.01$) in periods 1 and 2 and periods 2 and 3; no significant change can be detected between periods 1 and 3. No t-test was conducted for the rainfall variable since the results of the analysis of variance gave no significant changes.

The trends in extreme daily rainfall in the country are not statistically significant, although there have been changes in certain areas in the country. Likewise, the frequency of extreme rainfall exhibits an increasing trend, albeit the increase is statistically insignificant (Cinco et al., 2013). The projections by PAGASA on the frequency of rainfall predict that there would be fewer

rainfall events in most provinces in the country during the summer season, thereby making the usually dry season even drier (PAGASA, 2011).

The above findings in both monthly and yearly analyses for three decadal periods reveal significant changes in climatic patterns. This suggests that climate change occurred and were felt by the farm households in Roxas mountain range, City of Koronadal. Accordingly, this condition demands a transformative adaptation mechanism in order to reduce the communities' vulnerability and to build their resilience to climate change.

Community perception on climate change and its causes

Almost all (99.6%) of the respondents believe that the climate has changed in the past 30 years. More than half (58.6%) consider deforestation as the major cause of the changing climate. About 98.15% have noticed the abnormalities in rainfall and temperature patterns in the area. During the FGD, the participants relayed the historical climate variability extreme events experienced by the local people from the 1970s up to 2015 (Table 2). The occurrences of drought, flashflood/flood, and landslides are usually experienced, which have led to

Table 2. Historical climate-related extreme events experienced by the communities in Roxas Mountain Range, City of Koronadal, 1970–2015

Decade/Year		Type of event	Impacts of events on livelihood and people's lives
1970s	1973	Drought (7 months)	Crop failure
1980s	1982	Drought (9 months)	Crop failure
	1986	Flashflood	Crops affected Water level increased up to waistline
	1988	Drought (7 months)	No production
	1989	Flashflood	Three houses were washed up and destroyed
1990s	1998	Drought (7-8 months)	Plants dried/died Farmers have eaten <i>kayos</i> (wild yam)
2000s	2007	Drought (3 months)	Crop production affected
	2008	Flashflood	Houses destroyed
	2012	Landslides	Crop damaged
	2013		Property damaged (e.g., cars) Four persons died
	2015	Flashflood	Crop production affected
		Drought (4 months)	No harvest
		Landslides	Crops damaged Seven houses damaged

crop failures, damage to properties, and even loss of lives.

The Philippines, including the City of Koronadal, experienced in 2007 a two-month dry spell during the rainy season (July to August) (Yumul, Cruz, Dimalanta, Servando, & Hilario, 2010). These abnormalities consequently affected the cropping pattern of the smallholder farmers. The local farmers used to have two cropping seasons: one during the wet season from June to October (*panuig*), whereas the cropping season is planted during the dry season (*panolilang*). Farmers used to expect a very good harvest during the *panuig*, while harvest during the *panolilang* was considered just enough for their consumption. However, due to the abnormalities in rainfall and temperature and unpredictable weather conditions, there is no longer a clear demarcation between the two cropping seasons.

As observed by the respondents, the wet season has become wetter, thereby bringing floods and landslides in the study area. Similarly, the local residents have experienced intense heat during the summer, such that there have been instances when farmers could no longer work beyond 9 a.m. Moreover, there have been cases when the dry months have become the wet months.

Climate change impacts

The communities in Roxas mountain range have experienced yearly intense rainfall and temperature and have suffered prolonged droughts for 7–9 months which was observable within 5–10 years. The residents also experienced floods/flashfloods and landslides in August 2008, specifically in Barangays Carpenter Hill, San Isidro, and Saravia, and in Sitio Elgawel and Cabuling. These climate risks experienced by the communities are manifestations of climate change, which have caused socioeconomic and environmental impacts on the farming livelihood of the smallholder farmers.

Socioeconomic impact on farming livelihoods

Climate change has damaged the local farmers' crops, thereby substantially reducing their crop yield. Almost all respondents (96.6%) consider the decrease in crop yield as a major impact of climate change (Table 3). Likewise, the 2011–2015 data of the South Cotabato Provincial Agriculture Office cited that about 120 farmers in the study area experienced crop damage mostly due to heavy rainfall and flashfloods, thereby causing a lodge of corn and rice crops. About 40% total farming area (72.35 ha of 179.35 ha) were damaged during these events. As such, about 329 metric tons in

Table 3. Identified impacts of climate change on livelihood (Approach 2 Stage I)

Impacts	Brgy. Assumption (n = 17)		Brgy. San Isidro (n = 74)		Brgy. Paraiso (n = 52)		Brgy. Carpenter Hill (n = 58)		Brgy. Saravia (n = 64)		Overall Total: n = 265	
	Freq	%	Freq	%	Freq	%	Freq	%	Freq	%	Freq	%
Decline in crop yields	17	100.0	67	90.5	52	100.0	56	96.6	64	100.0	256	96.6
Occurrences of pest and diseases	17	100.0	71	95.9	51	98.1	47	81.0	50	78.1	236	89.1
Decreased working time in the farm	17	100.0	74	100.0	41	78.8	27	46.6	60	93.8	219	82.6
No production due to drought	17	100.0	54	73.0	52	100.0	34	58.6	61	95.3	218	82.3
Delay in planting	17	100.0	37	50.0	45	86.5	40	69.0	60	93.8	199	75.1
Reduced water supply	17	100.0	54	73.0	23	44.2	14	24.1	24	37.5	132	49.8
Loss of livelihood sources	13	76.5	12	16.2	7	13.5	2	3.4	43	67.2	77	29.1
Loss of and damage to properties and aesthetic	0	0.0	4	5.4	1	1.9	2	3.4	18	28.1	25	9.4
Loss of lives	0	0.0	6	8.1	0	0.0	2	3.4	3	4.7	11	4.2
Migration/transfer	0	0.0	1	1.4	6	11.5	1	1.7	26	40.6	34	12.8

production were lost, which translates to a monetary loss of PHP 3,962,947. Meanwhile, the cash assistance given by the LGUs to the affected families amounted to PHP 272,550.00.

The Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2014) cited that the *yield in staple crops* (e.g., maize, rice, and wheat) is projected to further decrease as temperature rises. Prices of agricultural commodities are also expected to be more volatile, and food quality would also further deteriorate due to climate change. Likewise, Cruz et al. (2017) mentioned that the variation in rainfall patterns and distribution are adversely affecting agricultural productivity.

Climate change has also *disrupted farm working schedule*. Approximately 82.6% of the respondents reported that they no longer follow their 7 a.m. to 12 p.m. farming schedule due to the intense heat and frequent occurrences of heavy rains. About 75.1% have experienced *delays in planting* due to the abnormalities in weather patterns. In addition, 82.3% of the farmer respondents said that they have *stopped planting crops* during extreme dry season and droughts, consequently leading to lack of income and hunger.

About 89.1% of the respondents mentioned that the climate change-induced *pest and disease infestation* is another factor that significantly reduces their crop yield. Based on the local farmers' experiences with upland rice farming, about 40%–100% of their production in a 1-hectare land is affected whenever pest and disease infestations occur. The pests and diseases that pervade the farmers' crops during the dry season include rats, black bugs, coconut beetles, bunchy top virus, leafhopper, aphids, fruit flies, corn borer, army worm, cut worm; meanwhile, leaf hopper and fruit and stem borer attack cereals and vegetable crops during the rainy season.

Climate change also has social impacts in the study area, as manifested in the *loss of human lives and properties* due to the flash floods in Barangay San Isidro in 2012. In addition, around 12% of the respondents relayed that they also *migrate temporarily* to other places during periods of drought.

Environmental impact on farming livelihood

Climate change has also directly affected the water supply in the research area as attested by about 49.8% of the respondents. The local residents observed that their water sources have been reduced, especially during periods of intense heat and drought. Apart from crops, physical structures of land resources have also been destroyed due to flashfloods and landslides, which destabilized the livelihoods of 30% of the farmer respondents. Moreover,

the flashflood in 2012 *damaged crops and livestock and destroyed landscapes* according to 9.4% of the respondents.

Current and potential transformative adaptation strategies

Current adaptation to climate change

The farmers in the study area have developed adjustment mechanisms in order to cope with the climate change-related stressors affecting their farming activities. Majority (84.5%) of the households have sought *off-farm work as an alternative livelihood source*. Such off-farm work includes waged labor, tricycle/scooter driving, trading, carpentry, construction, bamboo stick making (*tatad*), trading, and doing laundry work within the community. Many households (70.2%) have stopped planting due to crop failures, thereby abandoning their farms for a period of time. Some respondents have *shifted to planting other crops* like corn or rice to cassava and vegetables (58.1%), whereas others (46.4%) have *sought material or financial assistance from the LGU*. Some respondents (30.1%) have opted to *change their planting calendar*, whereas other households with financial capability/capacity *continued working at the farm* by planting trees/fruit trees.

Most of the respondents' current adaptation measures are just superficial solutions to climate change impacts—they do not resolve the underlying causes of climate change issues. Although integrating trees on the farm and seeking alternative livelihood options should be continued, the current adaptation strategies still need to be enhanced. Vital transformative adaptation strategies that are based on future climate scenarios and that consider the multifaceted drivers of climate change should be developed in order to protect and improve farming livelihoods.

Potential transformative adaptation to climate change

The 2011 PAGASA report projected that seasonal mean temperature would increase by 1.1–1.2 °C (2006–2035) and by 2.0–2.3 °C in 2050 (2036–2065). This projection is based on the downscaled climate scenario of South Cotabato province under the A1B medium range scenario. Moreover, the amount of rainfall is projected to decrease while the number of extreme events would increase in 2020 and 2050. The projected decrease in annual precipitation would be from –6.8% to –12.1% in 2020 and –6.8% to 18% in 2050 (PAGASA, 2011).

These projections and their possible impacts were presented to the community during the FGD and household survey. Accordingly, the potential transformative adaptations strategies identified.

Socioeconomic adaptation strategies

Adaptation varies based on the socioeconomic status and educational attainment of an individual. As such, majority of the farmers (61.5%) mentioned that *investing in children's education or in human capital* is one of the best potential transformative adaptation strategies to combat climate change. The farmer-respondents believe that this will have a spillover effect on their own economic and environmental conditions. Education enhances people's knowledge, skills, understanding, and behavior; thus, the farmers believe that investing in their children's education will help their children to have better jobs than their current unsustainable farming and forest activities (e.g., charcoal making). Educated children will sustain life and will help their parents to acquire innovative and sustainable farming system practices. In view of this, one measure to combat climate change is to *increase the number of scholarship grants* that local governments and other institutions provide to qualified students in the communities.

A few farmer-respondents (10.2%) said that *promoting more appropriate nonfarm alternative sources* is a good adaptation option to lessen their dependence on farming. Currently, when the household respondents cannot grow crops due to climate-related stressors, they do off-farm work (e.g., scooter driving, carpentry, waged labor) as alternative sources of income. The female workforce, together with their children, prefer making bamboo sticks, trading, and laundry work within the community. The city government of Koronadal has been providing trainings on nonfarm livelihood options (e.g., massage, spa manicure and pedicure, welding, food processing, etc.) to its populace. Despite this, however, there is still a need to further increase the number of beneficiaries and to explore more possible entrepreneurial, nonfarm livelihood activities based on available resources.

A few respondents (1.5%) also raised *family planning* as an adaptation strategy, while 18.1% mentioned that *knowledge on financial management or increasing personal savings* is an important aspect to consider in order to adapt to climate change.

Environmental/Biophysical adaptation strategies

One promising transformative adaptation strategy identified by the respondents during the FGD and household survey (46.8%) is *to enhance and to continue supporting the current practice of agroforestry or diversified farming system*. Agroforestry is a system that incorporates planting of trees or fruit trees and coconuts into farms as complementary crops to their annual main crops such as corn, rice, root crops. Likewise, raising livestock can also be integrated into their farming system. Aside from the socioeconomic benefits the system offers, the respondents mentioned that agroforestry has environmental benefits as well (e.g., balancing the temperature).

Agroforestry system is a sustainable solution to address the current and future climate change. It serves as both mitigation and adaptation strategy for enhancing smallholders' resilience (Uthappa, et al., 2018). As opposed to monocropping, this system assures continuous income from harvesting the complementary crop in times of crop failure of the main crop. The local people used to practice monocropping or planting single crops such as corn. Accordingly, smallholder farmers would be able to adopt agroforestry if they are provided with technical capacity development and planting materials.

Since 2009, the City of Koronadal has been conducting tree-growing festival activities every 29th of June. Different government and private agencies, farmer groups, and individual volunteers participate in this endeavor. This initiative promotes the stakeholders' collective efforts to protect and rehabilitate watershed areas. In 2019, the City of Koronadal celebrated its 9th tree growing festival, and the participants planted more than 100,000 seedlings (fruit and timber trees) to a 300-hectare land within the Roxas and Quezon mountain ranges (Estabillo, 2019).

Other adaptation strategies

About 43.8% of farmer respondents also suggested *establishing advance early warning systems (EWS)* that convey climate-related information to the local communities. In line with this, the city government of Koronadal has already set up an automated weather station (AWS) in 2013 to help monitor the weather patterns properly. The established AWS can capture weather-related data, such as rainfall, wind speed and direction, humidity, and temperature. This kind of EWS helps to reduce the impacts of climate change and to manage and reduce disaster risk. According to Travis (2013), early detection and warning systems for severe and/or abrupt climate change would benefit both adaptation and preparedness. This idea has then led the LGU and the communities to use the monitored data as a basis in enhancing the adaptive capacity of smallholders to climate change.

During the FGD, the participants also mentioned *water impounding or using water pumps to irrigate the crops* during the dry periods as an adaptation option since water supply is highly crucial in dry season farming. Other alternative adaptation mechanisms mentioned include *shifting to other crops* that are best suited to the changing conditions. These crops that thrive in intense heat include sorghum, cassava, and other roots crops. Farmers could also plant varieties that are resistant to pests and diseases and drought.

Conclusion

The findings for both monthly and yearly decadal analysis from 1981 to 2012 show significant changes and increasing trend in mean minimum temperature and decreasing trend in mean maximum temperature. An average increase of 0.74 °C in mean minimum temperature and decrease of 0.65 °C in mean maximum temperature were observable changes in three decades. The rainfall patterns during the same period also significantly changed, particularly in the months of June, August, and December. These suggest that climate change occurred in the Roxas mountain range, City of Koronadal. The farm households have observed and experienced extreme weather events, including intense heat, intense rainfall, floods, landslides, and drought. These manifestations of climate change have devastating socioeconomic and environmental impacts on the livelihoods of the farm households.

The current adaptation strategies of the farmers in the study area are mere temporary measures that do resolve the underlying causes of climate change. Hence, based on the PAGASA downscale scenario data, the possible impacts of climate change and the corresponding potential transformative adaptation strategies were identified. Accordingly, socioeconomic and environmental transformative adaptation strategies are necessary to reduce the adverse impacts of climate change. These adaptation strategies include *investing in children's education of the farmers and providing nonfarm livelihood opportunities*. Likewise, investing in the development of farm landscapes through *continued promotion of agroforestry farming practices/diversified farming, enhancing the technical skills of the farmers, and establishing advanced early warning system* are potential strategies for addressing climate change impacts.

Local government support plays a crucial role in increasing the stakeholders' awareness of climate change and in strengthening local leadership in protecting the environment. The findings of this study provide vital baseline information on climate-related impacts, which are necessary to enable policy makers to enhance the existing strategies and to further develop other adaptation strategies that will focus on climate-related stresses at the grassroots level.

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