



Characterizing the risk and impacts of tropical cyclones on banana production in the Philippines

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Abstract

The Philippines, a major banana producer, faces significant vulnerability to climate change and tropical cyclones (TCs), which caused over ₱352 billion worth of losses and damages to agriculture between 2000 and 2021. Banana is sensitive to strong winds and associated hazards. Climate change is anticipated to increase the intensity of TCs and thus has implications for the sustainability of banana production in the country. Banana is understudied in the context of food security, climate change, and its extremes. There are few studies that explore the linkages between TC impacts and its risk profile in the Philippines. Here, the physical risk of suitable and actual cultivated croplands for banana production is characterized following a risk-based approach to identify exposed and physically vulnerable areas to TCs. Data on TCs, banana production, and the costs of damages from TCs on the agricultural sector were also analyzed to provide a picture of current TC impacts. The analysis shows that TC risk is higher in Luzon and Eastern Visayas, which are exposed to more frequent and intense TCs, while Mindanao has a low calculated physical risk to TCs. Further research is needed to develop evidence-based strategies for climate change adaptation and disaster risk reduction.

Keywords: banana, climate change, impact, Philippines, tropical cyclone

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Highlights

- Banana production is an important agricultural activity in the Philippines. It is at risk to tropical cyclones. However, their impacts are under-studied.
- Here, the exposure and vulnerability of banana cropland is analyzed through a risk-based approach.
- While most of Mindanao has relatively low physical risk to tropical cyclones, the costs of damages to agriculture are rising, due to increasing exposure and vulnerability.
- Climate change will increase tropical cyclone activity and potential impacts on banana production. A greater research focus on adapting banana production and disaster risk reduction and management is needed, including understanding social and economic factors.

Introduction

Banana (*Musa* spp.) is a globally important fruit that is grown widely for food and trade. Together with plantains, bananas are among the top 10 crops in terms of area of cultivation, yield, and calories produced globally (Carr, 2009; Singh *et al.*, 2016; Varma & Bebbber, 2019). In the Philippines, banana is a significant source of nutrition and income, and the country is one of the largest producers of the fruit (Singh *et al.*, 2016; Varma & Bebbber, 2019).

As the banana crop is sensitive to temperature and precipitation (Carr, 2009; Robinson & Saucó, 2010), climate change and variability may cause significant changes in banana production. For example, high temperatures can cause damage to the plant and fruit, while low temperatures slow down growth and affect fruit quality. Changes to expected precipitation patterns will increase the risk of drought, which also affects production (Ortiz, 2012). Changes to temperature and precipitation patterns can also affect the incidence and distribution of pests and diseases such as Black Sigatoka and Fusarium wilt, which are of major concern to banana growers (Bebber, 2019; Salvacion *et al.*, 2019).

The Philippines, a major banana grower for both domestic and international trade, is at risk from these impacts; it is exposed and vulnerable to increases in temperatures, changes in precipitation patterns, and climate extremes (Villarin *et al.*, 2016). For example, the country is anticipated to experience increases in mean temperatures, on average, of 0.9–1.1 °C in 2020 and of 1.8–2.2 °C in 2050 (DOST-PAGASA *et al.*, 2020). In the Philippines, the Davao region in Mindanao is the center of banana production based on production and area (Department of Agriculture [DA], 2018). Climate

change projections for the Davao region show that maximum daytime temperatures will increase between 1.3 and 1.9 °C by mid-century under medium and high emissions scenarios (representative concentration pathways 4.5 and 8), and there will be 1–2 fewer wet days annually, meaning hotter and drier conditions in the region (DOST-PAGASA *et al.*, 2020).

A recent provincial-level multiple regression analysis showed that only 10% of the banana-producing areas in the Philippines are significantly affected by indices of temperature and precipitation (Salvacion, 2019), and based on this, climate change may have only limited impacts on banana suitability in the country (Salvacion *et al.*, 2019); however, this study argues that this may be because the range of favorable conditions for banana growing is wide and average climate indices are insufficient predictors of yield change. Indeed, the projected changes to average climate indices in the Philippines (DOST-PAGASA *et al.*, 2020; Villarin *et al.*, 2016) still place most regions within the growing thresholds for the crop (Robinson & Saucó, 2010), including the Davao region (Ortiz, 2012).

In the case of banana, the impacts of climate extremes may be more significant than changes to average temperature and precipitation. The Philippines experiences up to 20 tropical cyclones (TCs, also known as typhoons) per year, although they do not cross Mindanao frequently (Cinco *et al.*, 2016). The strong winds of TCs can blow down or uproot growing banana crops and cause significant losses and damages. Winds in excess of 40 km/hr are the single highest cause of losses in banana production, and wind velocities of more than 20 m/s can blow down 50%–100% of banana plants, which can take years to establish (Robinson & Saucó, 2010). The wind speeds of TCs greatly exceed this, with maximum sustained wind speeds exceeding 119 km per hour. TCs also bring other hazards, such as floods and storm surges, which can also cause significant losses and damages (World Meteorological Organization, 2022).

Despite TCs infrequently crossing Mindanao, recent years have seen increasing agricultural losses and damages in the region. In December 2021, Typhoon Odette (international name: Rai) caused billions of pesos worth of damage to the high-value crops in Mindanao. In 2012, Typhoon Pablo (international name: Bopha) caused major losses and damages in the Davao region. The banana industry incurred high losses from Typhoon Pablo, amounting to around ₱20 billion (US\$500 million), and thousands of banana growers lost their main source of livelihood in the Davao region (ReliefWeb, 2012). Typhoon Pablo was considered a “turning point” for the banana industry, and the recovery of the Philippines’ production rank globally took five years (DA, 2018).

Focus of the study

Climate change projections show that TCs may change

in their intensity, frequency, and other characteristics. Although there is a wide range of uncertainty in projections for TCs, model results show that TCs will generally increase in intensity, for example, to Category 4 or 5 on the Saffir–Simpson scale, meaning stronger maximum sustained wind speeds (Collins *et al.*, 2019; Gallo *et al.*, 2019); however, although it is an important crop globally, banana is understudied in the context of the impacts of climate change and variability (Varma & Bebbler, 2019). In particular, the impacts of TCs on banana production are poorly documented in scientific literature: A Scopus and Web of Science search for the terms “banana” AND “tropical cyclones” OR “hurricanes” OR “cyclones” yields little results typically outside the Philippines.

Because of banana’s role in nutrition and also in the national economy (Salvacion *et al.*, 2019), this knowledge gap is important to address for major growers like the Philippines. There is thus a need to characterize the current risks of Philippine banana production to TCs to aid in understanding future impacts and climate change adaptation. In light of the Philippine Banana Roadmap and orientation toward expansion and intensification of export-oriented agriculture (DA, 2018), increases in the area cultivated for banana production may be faced with rising risk from climate extremes like TCs.

This study aims to contribute to knowledge on TCs and banana production by providing a snapshot of current production and identifying areas of high physical risk using the risk framework of the Intergovernmental Panel on Climate Change (IPCC, 2012), where climate and disaster risk are products of hazards, exposure, and vulnerability.

Materials and Methods

Risk is an important concept in disaster risk reduction and climate change adaptation. People, assets, and infrastructure are affected by natural hazards depending on their exposure and vulnerability, which can be mediated by their adaptive capacity. To characterize this risk, the analysis is divided into two components: first, a national-level snapshot of current banana production and the agricultural impacts from TCs; second, a spatial analysis to develop a “score” for physical risk from TCs, with a focus on Mindanao and in particular the Davao region, as it has large amounts of land and production for banana and is the socioeconomic center for banana production (Figure 1).

National-level analysis

National-level data on banana production, TCs, and TC-induced economic losses and damages from the Philippines for agriculture were analyzed for the period 2010–2021 to provide a current characterization of banana production. The data were from the Philippine Statistics Authority (PSA, 2022). Part of the national-level analysis is an assessment of damages from TCs in the agriculture sector based on monetized damages. Unfortunately, most data on losses and damages from Philippine databases are coarse, aggregated to the national level, and available for the study from 2000 to 2021; however, this gives a snapshot of the impacts of TCs on the sector.

Physical risk of banana production from TCs

Following the IPCC risk framework, the hazard, exposure, and physical vulnerability of the cropland suitable for banana were analyzed in this study with

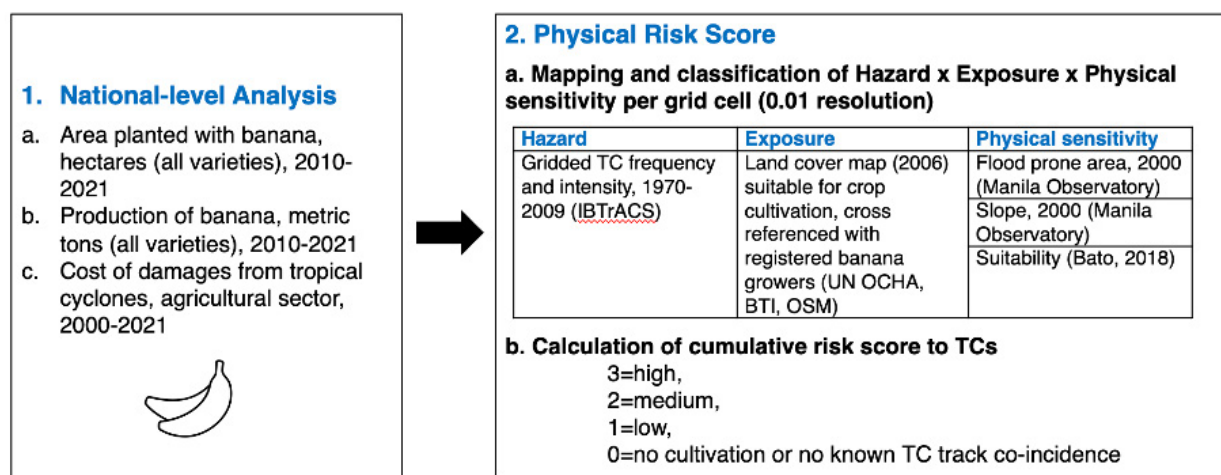


Figure 1. Study methodology and data sources

several biophysical indicators to provide a spatial characterization of risk. To represent the hazard to cropland, several datasets were utilized: high-resolution gridded datasets (0.01 degree) on TC frequency and wind speed to represent intensity from the International Best Track Archive for Climate Stewardship (IBTrACS) data from 1969 to 2009 (Knapp *et al.*, 2010; Knapp *et al.*, 2018), which is synthesized from data from the Japan Meteorological Association, Joint Typhoon Warning Center, UNISYS, Meteo France, and the Australian Bureau of Meteorology (United Nations Environment Programme, 2019).

In order to spatially represent TC-exposed cropland, the TC data were cropped and masked to agricultural land cover categories derived from the land classification from the United Nations Office for the Coordination of Humanitarian Affairs (2006). Land viable for banana included categories such as arable land, mixed cropland, cultivated areas, other cropland, and other plantations. These agricultural land cover data were validated using geographical data on registered Department of Trade and Industry (DTI) banana plantations from Ortiz and Torres (2020). These site plantation locations were derived from plantation data from the Bureau of Plant Industry and geolocated with OpenStreetMap (Ortiz & Torres, 2020).

Geophysical characteristics like slope and low-elevation zones were considered factors for physical sensitivity to hazards like strong winds and flooding. Slope was considered because of evidence of higher tree mortality and disturbance on windward surfaces with steeper slopes as a result of TC activity (Negrón-Juárez *et al.*, 2014). Flooding, storm surges, and inundation also affect banana production, as waterlogging has adverse impacts on the crop. Root systems could be permanently damaged or die after a few hours of waterlogging (Aguilar *et al.*, 2008). To account for this, flood-prone areas determined by low-elevation coastal zones were considered another factor for physical sensitivity.

Shapefiles and data provided by the Manila Observatory for slope and flood-prone areas (year 2000) were derived from data from the Philippine National Mapping and Resource Information Authority, the Mines and Geosciences Bureau, and the NASA/USGS Digital Elevation Model (SRTM version 4). Finally, a ranking system for each of the components was created, from high to low, including zero (3 = high; 2 = medium; 1 = low; 0 = e.g., no overlap with TC or no cultivation) to form a physical risk map to TCs (See Figure 1). The data were scaled, combined, and reclassified for each variable considered. All analysis was carried out with R version 4.0.3 using the *raster* package. The resulting risk map was compared to previously published work on banana suitability, which also considered average climate and soil type in addition to elevation and other topographic factors (Bato, 2018), but not TC exposure nor its intensity.

Data limitations

The study uses long-term TC analysis from 1969 to 2009 (40 years), which allows for a climatological characterization of TC activity. Although more recent TC data are available from IBTrACS, this time period is chosen for the analysis as land cover data for the Philippines is centered around 2006, and matching these two datasets is important to not overestimate or underestimate risk; however, this excludes more recent typhoons from the analysis.

The IPCC risk framework accounts for vulnerability, which is reduced by adaptive capacity, which is not included in the analysis. There are many proposed indices to represent agricultural vulnerability and adaptive capacity (Kozicka *et al.*, 2020), especially those that consider the characteristics of social vulnerability and adaptive capacity of farmers. In particular for banana, this may be closely related to how farmers address and manage banana disease, which can increase banana farming systems' vulnerability (Kozicka *et al.*, 2020), while access to different forms of capital (natural, physical, financial, social, and human capital) can improve adaptive capacity (Kuchimanchi *et al.*, 2021).

Here, the study focuses on the physical sensitivity of the agricultural land to primarily consider the characteristics and interactions of the land and its use that contribute to risk. Including socioeconomic indicators of risk and adaptive capacity will undoubtedly provide more depth and nuance to the understanding of risk, but the objective of the study is to characterize the physical components primarily to identify areas of physical risk. Future work will subsequently incorporate appropriate indicators for socioecological vulnerability, including farmers' adaptive capacity.

Results

National-level banana production, area cultivated, and TC damages

An analysis of agricultural statistics shows that the area cultivated for bananas in Mindanao accounts for more than half (56%) of all production in the country (Figure 2). The most current year of data (2021) accounts for 450,000 ha cultivated with banana (all varieties). A linear trend analysis showed that there are significant positive trends for the amount of area cultivated in Mindanao and in the Davao region over the 2010–2021 period; however, the annual cultivated area for the entire country does not show any significant trend. It can be observed that after 2012, there was a large drop in production caused by Typhoon Pablo, as reported by the DA (2018). Banana production recovered to its pre-Typhoon Pablo levels five years later, in 2017.

In terms of production, Mindanao accounts for 80% of all bananas produced in the country, with the Davao region alone contributing 39% to the total production of all types of bananas in the Philippines (Figure 3). A linear trend analysis showed that the Philippines and

Mindanao do not have any significant trend in terms of their annual production and that the Davao region has a significant negative trend for production over the most recent decade.

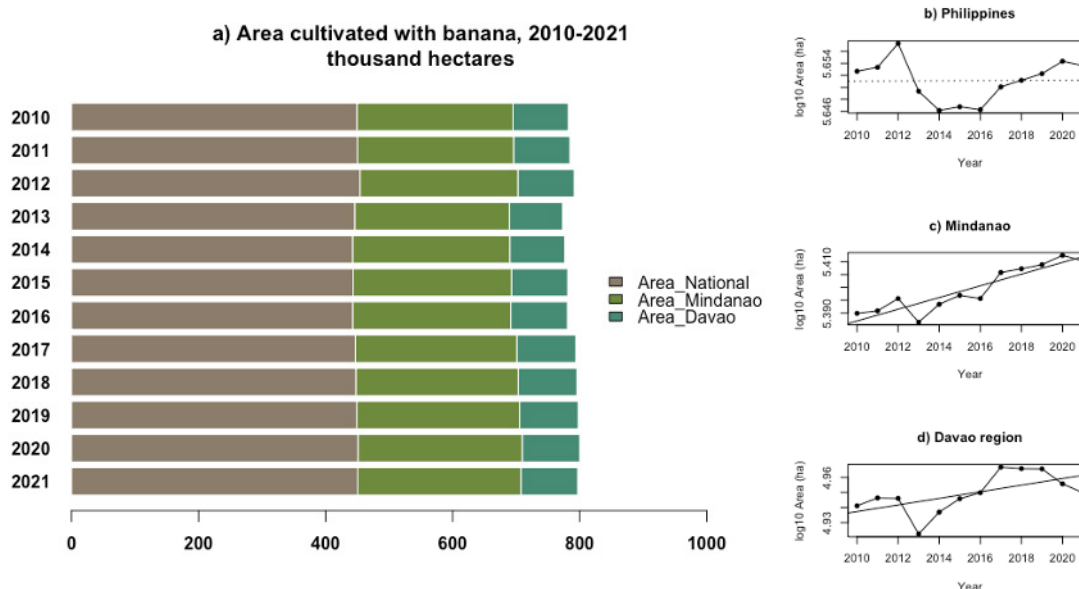


Figure 2. (a) Area cultivated with banana in thousand hectares, 2010–2021. **(b–d)** Area cultivated with banana in time series for the national level and for Mindanao and Davao region. A dotted trendline indicates a nonsignificant trend ($p > 0.05$), while a solid line indicates a significant trend ($p < 0.05$). Data from PSA (2022)

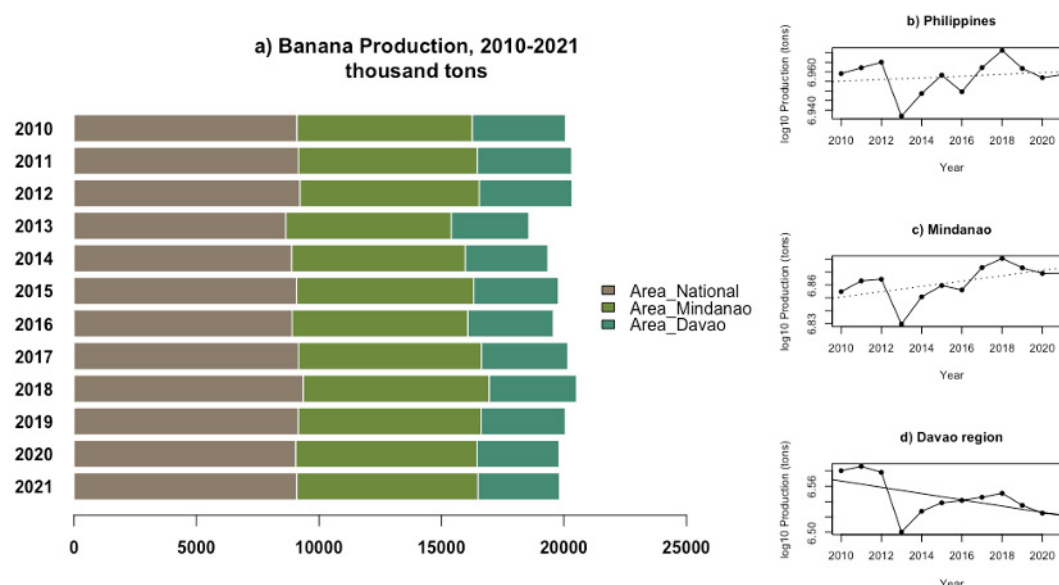


Figure 3. (a) Volume of production for banana in thousand metric tons, 2010–2021. **(b–d)** Volume of production for banana in time series for the national level and for Mindanao and Davao region. A dotted trendline indicates a nonsignificant trend ($p > 0.05$), while a solid line indicates a significant trend ($p < 0.05$). Data from PSA (2022)

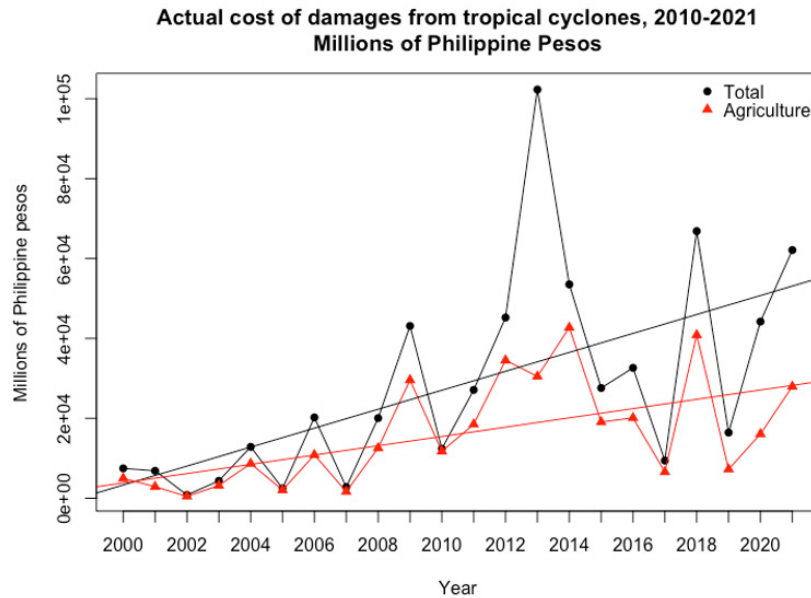


Figure 4. Area cultivated with banana in thousand hectares, 2010–2021. **(b–d)** Area cultivated with banana in time series for the national level and for Mindanao and Davao region. A dotted trendline indicates a nonsignificant trend ($p > 0.05$), while a solid line indicates a significant trend ($p < 0.05$). Data from PSA (2022)

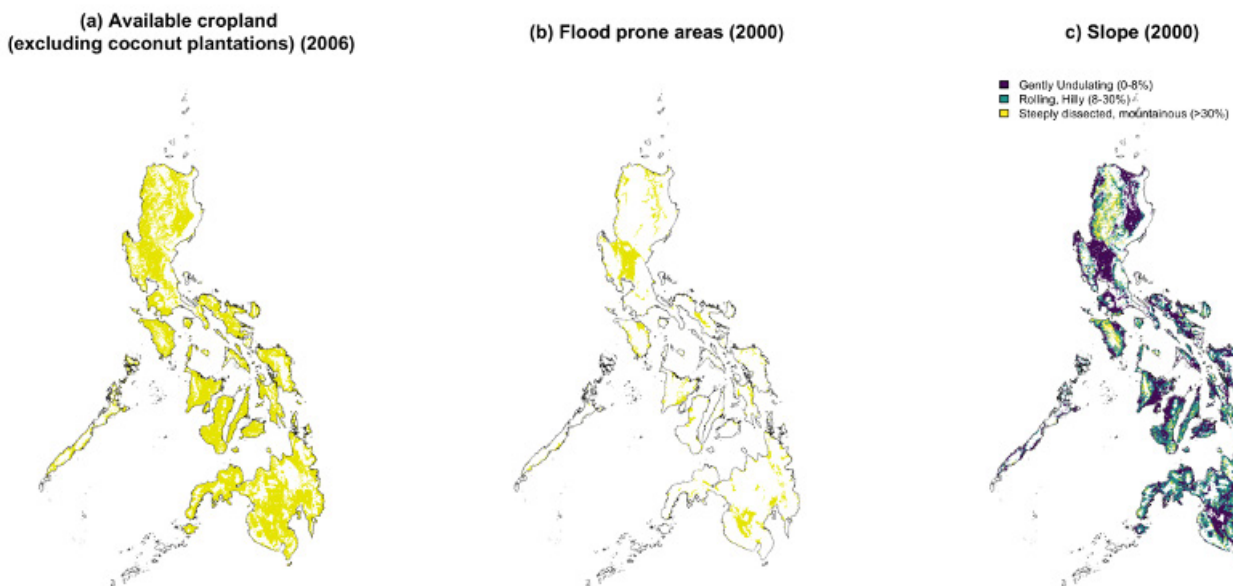


Figure 5. Components of physical risk: exposed available cropland, excluding exclusive **(a)** coconut plantations, **(b)** flood-prone areas, and **(c)** slope

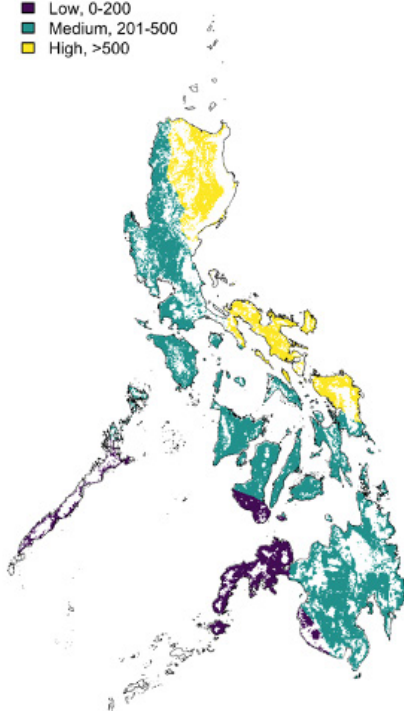
An analysis of agricultural damages from the Office of Civil Defense (OCD) shows that losses and damages to the entire agricultural sector (not available for single crops) caused by TCs were a total of ₱352 billion for 2000–2021 (Figure 4). The years 2010, 2005, and 2014 had the largest proportion of agricultural damages compared to the total cost of damages (95, 84, and 80%, respectively).

Hazard, exposure, and physical sensitivity

The geographical analysis of available cropland, flood-prone areas, and slopes (Figure 5a–c) shows that there is a considerable amount of land utilized for agricultural cultivation throughout the Philippines. There was a good agreement between DTI-registered banana plantation sites and cropland available for banana production. The flood-prone areas showed that there are many

a) Sum TC wind speed, 1969-2009

Low, 0-200
Medium, 201-500
High, >500



b) Total TC frequency, 1969-2009

Low, 0-25
Medium, 25-50
High, >50

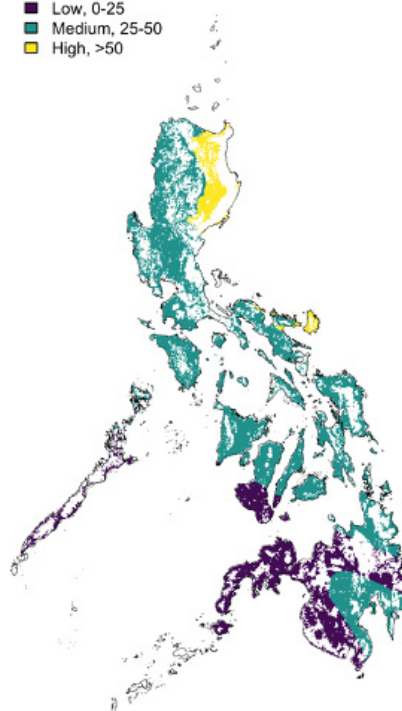


Figure 6. Characterizing the hazard by the (a) sum of total TC wind speed and the (b) total TC frequency from IBTrACS data, 1969–2009

Score of cropland physical risk to TCs

High
Medium

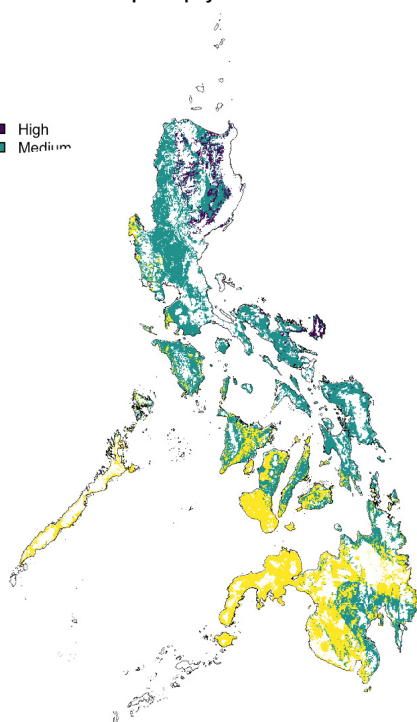


Figure 7. Physical risk score of croplands to TCs based on the risk framework: high (purple), medium (green), and low (yellow)

High
Medium
Low

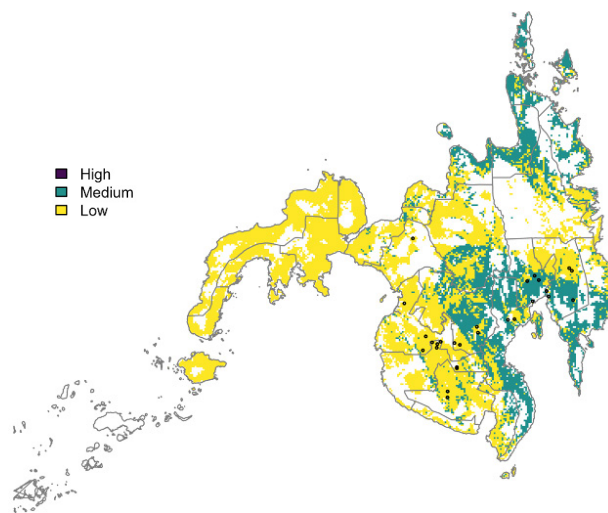


Figure 8. Mindanao TC risk score. Circles indicate registered banana plantations

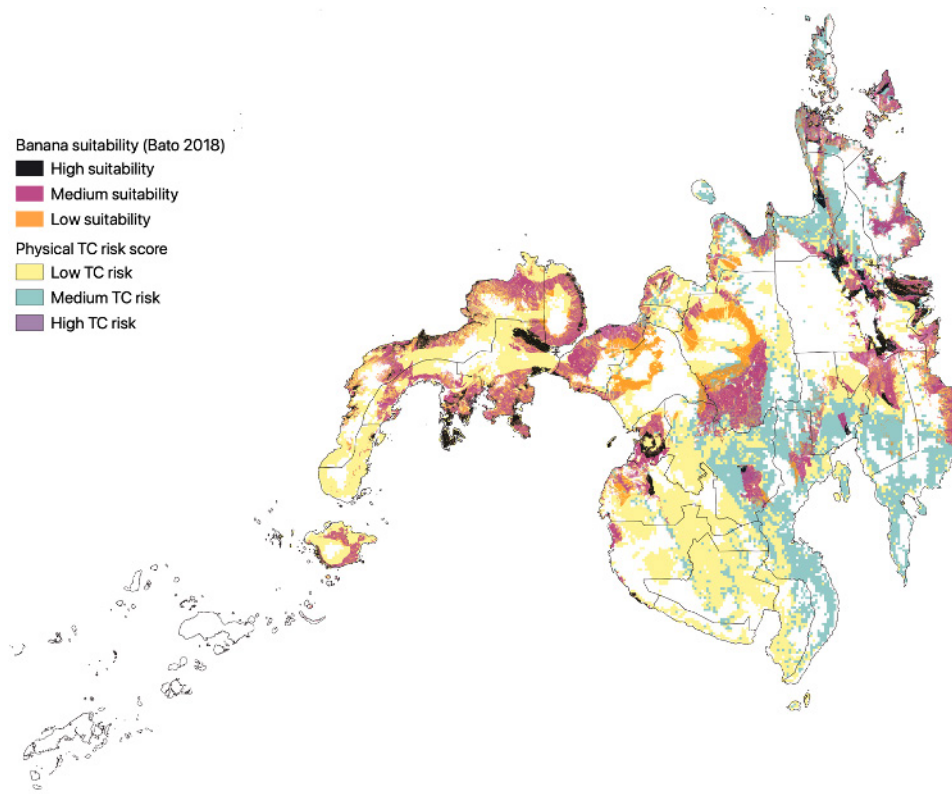


Figure 9. Characterizing the hazard by the (a) sum of total TC wind speed and the (b) total TC frequency from IBTrACS data, 1969–2009

low-elevation coastal zones around the Philippines. In Mindanao, there are large contiguous tracts of gently sloping land available for agriculture. It can be observed from the IBTrACS data from 1969 to 2009 that stronger winds associated with TC activity were experienced in Luzon, on the Pacific-facing eastern coast that is part of Regions II, V, and VIII (Figure 6a and b). Comparatively, Mindanao received low wind speeds over the 40-year period.

Estimated TC physical risk score

The spatial analysis shows that there are varying levels of TC risk across the country but generally low physical risk to TCs in Mindanao (Figures 7 and 8). Being in greater proximity to storm tracks, flood-prone areas, and sloping areas can augment the risk of losses and damages from TCs. This indicates that registered banana plantations in Mindanao are generally located in areas of current low risk. The highest risk to banana production from TCs is in Luzon, particularly parts of Regions I, II, V, and VIII, compared to Mindanao. This is because of the higher frequency and intensity of TCs passing through this region.

Combining the banana suitability map (Bato, 2018) and the TC physical risk map showed that the areas of highest determined suitability are in the Caraga region (Region XIII) and parts of the Zamboanga Peninsula, with the lowest suitability around Mount Kitanglad (Figure 9).

Discussion

The analysis of TC data and components of physical risk (hazard, exposure, and physical sensitivity) showed varying levels of risk of TCs in suitable banana cultivation areas across the Philippines. In general, there are low levels of risk in Mindanao, where banana production is concentrated (80% of all banana cultivated area; see Figure 2); however, despite this low-risk score, the large concentration of production, assets, and cropland from the banana industry in Mindanao, particularly in Davao and Caraga regions (DA, 2018), means that when a TC does occur in the region, there can be significant damages and impacts due to higher exposure. For example, recent analyses show that between 1990 and 2021, the annual number of TCs has declined globally; however, losses and damages have significantly increased, likely due to population growth and the higher value of coastal assets (Klotzbach *et al.*, 2022). This is also the case in the Philippines: While TCs did not show significant trends

between 1951 and 2013, losses and damages increased significantly (Cinco *et al.*, 2016).

The projected increases in the intensity of TCs, fueled by climate change, mean that these damages could continue to increase. This may also be affected by the changing exposure and vulnerability of these agricultural lands to strong winds and flooding. More powerful typhoons, as well as climate change, will continue to bring hazardous weather and increase the risk of unfavorable growing conditions for banana production in the Philippines.

Following the IPCC framework on climate and disaster risk (IPCC, 2012), banana production in the Philippines is increasing its risk of climate change not only because of the changing hazards but also because of the increasing area of agriculture. Land use change itself due to banana production can have significant impacts on biodiversity (Ortiz & Torres, 2020). Growth and expansion of banana cultivation are likely to mean greater exposure of the banana crop to changing climate conditions and TCs, even though risks remain low to moderate at present. This is supported by the increasing area cultivated with banana in the Mindanao region, which showed a significant positive trend.

Despite this importance, the Philippine Banana Industry Roadmap (DA, 2018), while it mentions climate change and its extremes as a problem, falls short in recommending strategies and evidence-based measures for adaptation, which are included in its roadmap goals. While studies outside the Philippines have suggested some measures for pre- and post-TC management (Lindsay, 2016), actions for agriculture need to consider local context and capacities. These are areas that are important for developing future studies, including understanding the socioecological vulnerability of banana production.

In order to do so, it is important that local-scale data (e.g., provincial or regional damage assessment) become available to develop a more localized risk profile that includes vulnerability and adaptive capacity. For example, this study is limited by the availability and accessibility of more disaggregated data available for public use, including fruit crop-specific damages. Importantly, many of the key maps can already be considered in need of an update, particularly for land use. It is recommended that open-source data related to environmental land use be regularly updated and made available for research and public information.

Conclusion

TCs are powerful hazards that can have significant impacts on banana production in the Philippines due to the sensitivity of the crop to strong winds and other associated hazards. Based on an analysis of data from the most recent two decades, the agriculture sector as a whole has sustained ₱352 billion in economic losses and damages. The current risks from TCs across the country

are varied, given the Philippines' diverse geographies and levels of cultivation. Mindanao is the center of banana production in the Philippines, as it accounts for the majority of all bananas produced in the country. Based on the risk score analyzed here, the physical risk to TCs is currently low in Mindanao; however, climate change and its extremes could change this, as they are projected to become more powerful and have greater variability.

In order to adapt to climate change and its extremes, there need to be evidence-based approaches to reducing vulnerability to climate change and its extremes. Therefore, how the physical sensitivities to climate extremes like TCs interact with farmers' and producers' vulnerabilities and adaptive capacities should be an area of active research, especially in the context of climate change and variability.

Another area for future research would be to project changes to crop suitability based on downscaled projections of climate change, including average climate indices but also extreme events such as TCs (see, e.g., Gallo *et al.*, 2019). Currently, national and regional policies are oriented toward increasing and intensifying agriculture to become more output oriented; however, they should also consider how future risks, including climate change and its extremes and more favorable conditions for pests and diseases (e.g., Black Sigatoka and Fusarium wilt; see Bebbber, 2019 and Salvacion *et al.*, 2019), will affect the long-term sustainability of the crop. Greater inclusion and research focus around banana are needed, given the dearth of studies around one of the world's and the Philippines' most important fruits.

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