Climate vulnerability scenario of the agricultural sector in the Bicol River Basin, Philippines

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Abstract

This paper investigated the vulnerability of the agriculture sector and rural agriculture livelihoods in the Bicol River Basin (BRB) of the Philippines to projected changes in climate. The geographical characteristics of the BRB feature eight major sub-basins or watersheds consisting of Libmanan-Pulantuna, Ragay Hills, Thiris, Naga-Yabo, Pawili River, Waras-Lalo, Naporog, and Quinali. The study applied the combination of the participatory tools and the Climate Risk Vulnerability Assessment (CRVA) framework to gather information on local climate vulnerabilities and contexts. Briefly, the CRVA employed geospatial modeling and utilized several indicators which are presumed to affect vulnerability including exposure, sensitivity, and adaptive capacity which were aggregated to provide an index of vulnerability. This enabled us to identify areas of exposure and vulnerability and pointed areas of greatest need for strengthened adaptive capacity and risk management. Our findings revealed that vulnerability in the BRB was perceived to be relatively prevalent and that typhoons, flooding, and drought were identified to contribute significant impacts to rural livelihood. Furthermore, our findings in the CRVA suggested significant regional differences in vulnerability in the BRB. The majority of the towns in the central and northwestern portions of the BRB will largely experience increased vulnerability, particularly, in the Thiris sub-basin including some parts of Ragay Hills, Waras-Lalo, and the northwestern Libmanan-Pulantuna sub-basins. On the contrary, the entire Quinali region on the south is revealed to have the lowest vulnerability index. The clear policy implication of these accounts will be on how to mobilize developmental thrusts in both areas of disaster risk reduction and climate change adaptation at the sub-national level to reinforce local-based climate priority setting in adaptation interventions and policies.

1. Introduction

Known for its agricultural capacities, the Philippines' complex geographical location and archipelagic formation where exposure to different abiotic stresses such as extreme solar radiation, sea-level rise, and ill-effects of meteorological-related hazards (Doroteo 2015; Mascariñas et al., 2013; World Bank, 2013; Peñalba, et al., 2012) are mostly experienced, has long posed a substantial amount of concern and significant impact on the spatial and temporal aspects of agricultural productivity. The erratic climate variability and extremes in the country are known to be largely modulated by the El Niño–Southern Oscillation, or ENSO, an interannual perturbation of the climate system characterized by variations in the temperature of the surface water and air surface pressure of the eastern and western Pacific Ocean, respectively, which in turn creates a pronounced effect on agricultural productivity (Stuecker, et al. 2018; Alberto, et al. 2012). Although the effects of climate change, some of which can be attributed to anthropogenic climate change, are expected to vary geographically, poor and vulnerable small-scale farmers can expect increases in the volatility of weather patterns, severe weather events (including increased drought and flood risk), and increases in mean temperature and rising sea levels (Jost et al., 2015) especially in a meteorologically hazard-prone country like the Philippines.

Identifying climate change vulnerability requires a clear conceptual framework and to strengthen the capacities of selected communities in the Philippines, a preliminary identification and situational assessment of the areas most vulnerable to climate change risks is the primary task to be done to gather baseline information about the communities' vulnerability and the factors determining them.

Here, we provided a vulnerability assessment of one of the major river basins in the Philippine archipelago— the Bicol River Basin also known as the BRB (Figure 1). The basin plays a crucial role in the development of the region because of its abundant resources and the ecological services it provides to support the livelihood of communities. About 77% of the basin area or ~244,160 hectares are cultivated agricultural lands, its rivers and lakes provide irrigation water to these lands, apart from being used for fishing. The forests and forestlands, including protected areas, contain rich biodiversity resources and non-timber products, which are used as raw materials for handicrafts. The major rivers and tributaries of the BRB, likewise, provide sources of water for irrigation, domestic use, and power generation. With the vast area covered by the river, millions of pesos (PHP) in damage in agriculture and fisheries are experienced perennially by the communities living along it, largely due to climate change (DENR, 2015).

To date, most literature regarding BRB studies is already outdated spanning from the 1970s–1990s (Illo, 1977; McKee, 1983; Koppel, 1987; Lanzona et al., 1997). Additionally, the majority of studies (Herrin, 2019; Rola, et al., 2018; DENR, 2015; Abon, et al., 2012; Meigh & Bartlett, 2010; Usamah & Alkema, 2006) conducted in the BRB are mostly limited to socio-economic profiling and analyses, inventory of biophysical resources, hazard-risk assessments, management regimes and/or the combinations thereof. Motivated by these considerations, we employed a combination of participatory social research methods and the Climate Risk Vulnerability Assessment (CRVA) framework using the latest geospatial modeling through the use of GIS data, and selected agricultural commodities for the ecological modeling and their interaction within the spatial model structure to assess the current vulnerability scenario of the BRB and the components that is closely interlinked with vulnerability. The participatory approach was proposed to qualitatively understand the local vulnerability perceptions and climatic contexts of the region and accordingly, the CRVA approach was employed to quantitively determine the main hotspots of vulnerability as the function of exposure, sensitivity, and adaptive capacity. Although a wide range of methodological frameworks and approaches have been developed and executed to analyze climate vulnerabilities based on the resources and production systems, timeframe, and geographic coverage, so far, we noted that the combination of the methodologies mentioned has not been fully documented in the literature and thus, provides innovation to the application of this case study. Since river basins are documented to be highly susceptible to climate change (Dilshad et al., 2019; Johnson & Hutton, 2014; Gohari et al., 2013), the study intends to contribute to the limited knowledge in one of Philippines' most vulnerable yet very productive area and provide a clear visualization of the current climate scenario of the vulnerable agri-fishery communities living within the Bicol River Basin to identify at the administrative level which areas are most vulnerable to the projected impacts of climate change on agriculture and recommend interventions for future policy directions.

2. Methods

2.1. Study area description. The Bicol River Basin (BRB) is an integrated agro-watershed ecosystem that geographically extends from 13°0' – 14°0' N to 123°0' – 124°0' E representing about 317,103 hectares of the land area of the mainland Bicol Region in the Philippines and largely embraces the provinces of Albay, Camarines Sur, and Camarines Norte. The basin encompasses forty municipalities and three component cities situated wholly or partially within the agro-river system and categorically divided into eight sub-basins namely, Libmanan-Pulantuna, Ragay Hills, Thiris, Naga-Yabo, Pawili River, Waras-Lalo, Naporog, and Quinali for managerial regimes. The distinct geomorphological features found in the area include major geologic formations, which allow it to be naturally divided into the Bicol Plain, the Sedimentary Terrain on its southwestern side, and Volcanic Terrain found on the eastern rim bounded by a cordillera of five volcanic mountains. The BRB is drained by a network of rivers and lakes and principally by two major rivers: the Bicol River and Libmanan River which finally empty into the San Miguel Bay situated on the northeast. The climate in the BRB is fundamentally governed by three prevailing types of climatic variations: (i) no dry season with very pronounced rainfall from November to January; (ii) rainfall more or less evenly distributed throughout the year; and (iii) not very pronounced dry season from November to April and wet during the rest of the year, for the upper portion, the central strip, and the lower portion of the BRB, respectively.

2.2. Participatory analysis of stakeholders' perception. Participatory and qualitative research methods such as Participatory Rural Appraisal (PRA) and Capacity Analysis, Focus Group Discussions (FGD) with the multisectoral members of the community, key informant's interview (KII), and participant observation were employed in the study adopted loosely from the study of Gentle & Maraseni (2012). To analyze and gain the perception of the stakeholders towards vulnerability, the vulnerability matrix as a qualitative tool was employed, briefly, major climate hazards and livelihood resources were identified and listed in a matrix by the respondents. In this matrix, the major hazards and most impacted livelihood resources were prioritized. Scoring for the hazards against the livelihood resources was carried out based on a Likert scale indicating the severity of impacts brought about by the identified hazards, which were represented by numerical values that correspond to a certain degree of impact (i.e. significant, moderate, minimal, and no impact). Accordingly, the identified respondents in this process were farmer groups and irrigators' associations, fisherfolks (lake, river, estuary, and coastal/marine fishers), private enterprises, local government agriculture service providers, local disaster risk reduction, and management authorities including agrometeorological experts operating within the BRB.

2.3. Crop selection and collection of occurrence data. In this section, geographic information system (GIS) data which were mainly free and open-source data at the finest spatial resolution possible were collected and organized by scale from global to sub-national (province to district) level (see summary in Supplemental Table S1). In terms of national and sub-national data collection where data distribution is protected by data privacy protocols, the figures sourced out from various governmental agencies and instrumentalities were treated with discretion and utilized exclusively for scholarly and management purposes.

Additionally, with regards to the selection of cash crops to be utilized in the assessment, economically essential agricultural commodities that are principally cultivated in the BRB were prioritized based on the region-based census by the Department of Agriculture-Bicol (2017) and the Philippine Statistics Authority (2019, 2018, 2012). The study identified and utilized five priority agricultural commodities for the assessment namely rice, corn, cassava, taro, and tilapia. In order to prioritize which commodities to include in the CRVA, the identification was based on two main factors: (1) crops are important for food security, and (2) crops are important sources of cash. Additionally, the selection was also influenced by the crop's local market demand and its potential for value-adding products, access to primary processing facilities and storage, and crop's suitability to the local climate such as temperature, rainfall, and other agro-ecological conditions. To assess the distribution of these commodities, Species Occurrence Points (SOPs) were obtained from existing crop occurrence archives and mostly from local experts through a participatory mapping workshop. The mapping exercise was designed to rapidly collect data from the field. Participants achieved identification of crop location based on personal knowledge, familiarity, and similarly relevant records and pieces of literature. The resulting intermediate analog data plots were digitally exported on Google Earth and afterward, integrated into the spatial model to enable further modeling and analyses. Validation was achieved through a series of consultations both with the experts and the immediate recipients of the generated putative maps.

2.4. Vulnerability assessment. In this section, we outline the approach as to how the multiscale spatial data within the three components of vulnerability has been aggregated to obtain an index of vulnerability following the framework of the International Center for Tropical Agriculture (CIAT) specifically from the works of Parker et al. (2019). Modifications from the adopted framework were implemented to tailor the Philippine scenario, specifically by developing appropriate weights per vulnerability component, by using different sets of indicators for exposure 2 and adaptive capacity, and using a different vulnerability equation (Eq. 1), among others (Figure 2). We would also like to note that the pooling of some datasets from different sources as well as the capacity building was sourced out and sought from CIAT-Philippines through the CIAT-AMIA project (CIAT, 2016). The processes involved in the aggregation were outlined in Figure 2.

2.4.1. Exposure assessment. For this component, we further compartmentalized exposure into two components: first, we estimated the changes in temperature and precipitation between future projection (decade 2050) and the current or baseline conditions. And second, we factored in several biophysical indicators which correspond to the natural hazards exerting higher pressure to the agricultural sector and rural livelihoods such as tropical cyclone, flood, drought, saltwater intrusion, erosion, landslide, sea-level rise, and storm surge.

With regards to Exposure 1, in estimating the current or baseline conditions, we used the global database WorldClim (Hijmans et al., 2005) which contains a high spatial resolution of weather and climate data. Using this database, spatially interpolated gridded climate data using thin-plate splines algorithm consisting of monthly total rainfall, and maximum, mean and minimum temperature, were aggregated across a target temporal range of 1950–2000 (Fick and Hijmans, 2017) to provide an estimate to the current scenario. For the future climate projection, we used a set of global climate data from a mean ensemble of 33 General Circulation Models (GCMs) (see Supplemental Table S2) under two global climate scenarios, that is, the Representative Concentration Pathways (RCP) 2.6 and 8.5 based on the IPCC AR5 WGI (2013). The RCPs form a set of greenhouse gas concentration and emissions pathways to produce a range of responses to the ongoing warming (Gang et al. 2015) and designed to support research on impacts and potential policy responses to climate change (Moss et al. 2010; van Vuuren et al. 2011). In this study, the utilization of RCP2.6 and RCP8.5 provides us with an estimate of the lower bound and upper bound risks, respectively. The changes in precipitation and temperature were then calculated by subtracting the current to future climate scenarios to provide an overall estimation.

In terms of the approach to Exposure 2 also known as 'exposure to hazards', spatially aggregated datasets of the identified natural hazards were acquired from national sources (see Supplemental Table S1). Local experts consisting of agriculturists, DRRM experts, and representatives from the academe were involved in the CRVA studies in the Philippines. Since each hazard has different degree, intensity and frequency, the potential damage also varies, especially across the three main islands of the Philippines, i.e., Luzon, Visayas, and Mindanao (herein referred as "island groups"), hence each of the hazards were weighed in each of the island groups. Different weights were assigned to each identified hazard (see Supplemental Table S4) with respect to the three island groups based on probability of occurrence, impact to the national economy, impact to food security of the country, impact to local household income, and finally, impact to key natural resources to sustain productivity (i.e., water quality & quantity, biodiversity, soil fertility). Scoring for the hazard weights was represented by numerical values (1-5) that correspond to an adjectival interpretation. In terms of the probability of occurrence: once in every year, once in every 5 years, or once every 10 years or more, were used. Accordingly, insignificant, minor, moderate, significant, or disastrous, were used for impact. For this study, we only utilized the weighted values for Luzon Island since the BRB is situated solely within the Luzon region. Finally, to generate the hazard index, the mean values of aggregate weight for each municipality were computed. Normalization was employed to rescale all the values from 0 to 1. Accordingly, five equal breaks were used to establish the thresholds for the following classes: 0–0.20 (Very Low), 0.20–0.40 (Low), 0.40–0.60 (Moderate), 0.60–0.80 (High), and 0.80–1.00 (Very High).

2.4.2. Sensitivity assessment. Crop sensitivity was assessed by analyzing changes in climatic suitability of crops by the year 2050 in comparison with the current crop suitability. For this study, sensitivity is described as the change in the climatic suitability of an area to grow a crop (Parker et al., 2019). To estimate this change, we subtracted the future climatic suitability from the current suitability. To model the climatic suitability of individual crops, we utilized the MaxEnt model (Elith et al., 2011) for rice, corn, cassava, taro, and tilapia since this model has been seen to perform well for crops that are often irrigated (Parker et al., 2019). Accordingly, this modeling approach is a niche-based model that assumes the distribution of observations, i.e., presence data and represents the realized niche (Heumann et al., 2011).

For current/baseline conditions, the WordClim dataset (available at Worldclim.org) (Hijmans, 2005) was used. A total of 20 bioclimatic variables were selected to assess the climate suitability of crops (described in Supplemental Table S3) representing annual trends, seasonality, and extreme or limiting environmental factors. These described bioclimatic factors are relevant in understanding the species response to climate change (O'Donnell and Ignizio, 2012). Bio_20, a climate variable processed by CIAT, was added to the bioclimatic variables from WorldClim. These bioclimatic variables were integrated with the respective crop to produce climate suitability maps under current conditions and employed expert feedback to validate the accuracy of the map and its inputs. After which, the future projections (2050), using a set of 33 statistically downscaled GCMs for the RCP2.6 and RCP8.5 emission scenarios were each integrated into the niche crop model to generate 33 projected suitability outputs. From this, we computed the average and the standard deviation to assess the degree of variability of the GCMs. We finally calculate the change (%) between the current and projected suitability, extract the values for each administrative unit, and provided classifications in terms of the sensitivity indices. An index of -0.25 – -1.0 means an increase in suitability while 0.25–1.0 means a loss in suitability. The index equal to 0 means there is no change in suitability detected or because there is just no crop presence.

2.4.3. Adaptive capacity assessment. In this study, adaptive capacity (AC) is understood as the ability of a system to adjust and respond to changes in climate. Among the three components of vulnerability, it is the aspect directly correlated with resilience. For this component, we compiled datasets (see Supplemental Table S1) for each of the respective attribute capitals (social, economic, health, human, institutional, natural, physical, anticipatory) derived from up-to-date available data mainly from 2015 and downscaled on the municipal level in the context of climate change effects to agriculture. The indicators enumerated in this study are flexible and very context-specific. In our case, it is very useful in providing an estimate as to the availability of resources vis-à-vis the absorptive capacity of the communities of each municipality. The values of the sub-indicators (Supplemental Table S1) were converted to a GIS spatial format by linking it to the shapefile municipal boundaries. Each of the indicators and sub-indicators were aggregated for each capital were treated with equal weights. The sum of the capitals was used as the adaptive capacity index. Values were normalized and five equal breaks were developed to show low to very high adaptive capacity: 0–0.20 (Very Low), 0.20–0.40 (Low), 0.40–0.60 (Moderate), 0.60–0.80 (High), and 0.80–1.00 (Very High).

2.4.4. Final vulnerability index assessment. In this section, we finally combined the different components of vulnerability consisting of the normalized values of exposure to natural hazards, crop sensitivity, and adaptive capacity to calculate the overall vulnerability at the administrative boundary scale. To determine the weighted contributions to each component, a balanced weight approach (Hahn et al., 2009; Sullivan, 2002) was used in this index. The weighting scheme can be adjusted to reflect the perceived importance of specific factors (Krishnamurthy et al., 2014). For example, as suggested by Eakin and Bojorquez-Tapia (2008), to determine the weightings for indicators we adopted values as a result of focus groups and expert workshops led by national experts through a national workshop to gain a consensus on the final weight to be assigned for each vulnerability component. As a result, the experts suggested an overall vulnerability assessment weights of "Hazards (15%)", "Sensitivity (15%)", and attributed the highest importance in defining vulnerability to "Adaptive Capacity (70%)".

The calculation and analysis were subsequently carried out and mapped on QGIS 3.4 (Madeira) software. After assimilating the assigned weights to each respective component indices, the overall vulnerability was determined by aggregating the indices of the potential impact (Haz + Sensi) and adaptive capacity (AC). For this, we employed the equation presented below.

$$Vulnerability\ index = \sum_{i=1} [Haz(w_h)] + [Sens(w_s)]_i + [1 - AC(w_a)] \qquad \textbf{Eq. 1}$$

Where: Haz = hazard index, $Sens_i$ = sensitivity index of the crop (i = crop), and AC = adaptive capacity index. w_h = weight given for hazard, w_s = weight given for sensitivity, and w_a = weight given for adaptive capacity.

Subsequently, expert validation was sought at various stages of the methodology (Figure 2); several stakeholders of every administrative unit participated in this consultation, consisting of agriculture service providers, DRRM, and planning officers. As a heuristic tool, in certain cases that the expert recognizes areas where the model presents certain inconsistencies or inaccuracies, we subsequently re-run the model incorporating the experts' recommendations and present the restructured results, we repeat this process until the maps capture the relative spatio-temporal conditions of each administrative area. This feedback mechanism is critical in order to improve the accuracy and validity of the maps generated. After obtaining the final validated scores, we subsequently summarized the distribution of vulnerability index scores through a kernel density plot and employed statistics using R software. We then categorized vulnerability according to the vulnerability score using the following conditions, Very Low-Low (Vulnerability $\leq$ 0.40), Moderate (0.425 $\leq$ Vulnerability $\leq$ 0.60), and High-Very High (Vulnerability $\geq$ 0.625).

3. Results And Discussions

3.1. Perceptions of vulnerability in the BRB

The present study aimed at contributing to the indigenous knowledge within the context of climate change adaptation. In this context, we initially conducted a species occurrence survey to assess the vegetation cover in the BRB. For this, we presented the occurrence points of priority commodities that are principally cultivated in the region (see Supplemental Figure S1). It can be distinctly noted that the majority of these crops are grown within the boundaries of the basin, most prominently in its central portion where almost all crops converge along the major rivers and tributaries where supplies of freshwater are discriminately abundant. Consequently, this creates an environment of uncertainty and presents a major concern to marginalized small-scale farmers since largescale inundation is the most pervasive hydrological hazard that threatens the extensive low-lying Bicol Plain (DENR 2015; Mascariñas et al., 2013; Abon, et al., 2012). As part of Climate Vulnerability and Capacity Analysis (CVCA), a vulnerability matrix was prepared to gain perceptions on the vulnerability of the agriculture sector from its grassroots level. The methodology helps to better understand the implications of climate change on community-level livelihoods and examines both hazards and conditions of poverty and analyzes the interactions between them. The approach supports the collection of locally specific information on risks, vulnerabilities, and capacities in relation to climate-related shocks, stresses, and uncertainties and facilitates analysis of this information in ways that can unearth differences based on socioeconomic characteristics that influence resilience (Daze et al., 2009). Participated by various stakeholders operating within the BRB, it was revealed that besides frequent flooding, 'typhoon' was perceived to contribute the most significant impact on the prioritized livelihood resources that arise from these communities. Notably, although water supply in the area should be considered sufficient because of the wide coverage of the Bicol River, the occurrence of drought still significantly affects the area. Additionally, the occurrence of saltwater intrusion in freshwater systems in the areas located along the low-lying coastal lands was also identified to be a potent contributor to the decreased productivity of major agricultural practices since it has been documented that soil biogeochemistry can be dramatically altered as saltwater intrudes these agricultural fields (Tully et al., 2019). These problems arise considerably due to water management facilities and infrastructures that are poorly designed, misaligned, operationally underperforming, or constructed disproportionately to function during such debilitating scenarios. The presence of pests and diseases, as well as farm vermin, were also identified to cause significant to moderate impact on major agricultural products these include pests such as the black bugs (*Scotinophara* spp.), stem borer larvae (*Scirpophaga* spp. & *Chilo* spp.), armyworms (*Spodoptera* spp.), and green leafhoppers (*Nephotettix* spp.) which also transmit the viruses that cause rice tungro disease and other various plant diseases such as mildew and anthracnose caused by fungi and bacterial blights. Other farm pests were also reported to cause major crop damages such as golden apple snails (*Pomacea canaliculata*) and other larger wild animals such as farm rats (*Rattus* spp.) and rice-eating birds (*Lonchura* spp. & *Passer montanus*). Accordingly, the most vulnerable livelihood determined by the stakeholders revealed to be rice cultivation followed by the high-value crops and then the livestock and poultry, based on the composite data (see summary in Supplemental Figure S2).

3.2. Main context of vulnerability

Given the rate and breadth to which climate change is already exerting increased pressure upon many vulnerable communities (Gentle & Maraseni, 2012; Laukkonen, et al., 2009), and the relatively finite resources available to various stakeholders to mitigate its impacts (Buchner, et al., 2017), it is of paramount importance that interventions are strategically planned and implemented (Weis et al., 2016). Over the past decade, there is an increasing body of literature that focused on evaluating the vulnerability of various sectors to climate change, including agriculture (Jurgilevich, et al., 2017; Mallari, 2016; Acheampong, et al., 2014; Wu, et al., 2011; Ford, et al., 2010). Characterizing vulnerability is central to identifying adaptation needs and informing adaptation policy development (Ford, et al., 2010). It is integral, therefore, in all vulnerability assessment undertakings to keenly understand what constitutes vulnerability; several studies (Vos, et al., 2016; Baca, et al., 2014; Füssel, 2010; Deressa, et al., 2008) have adopted what seems to be the most authoritative (Hinkel, 2011) definition of vulnerability developed by the Intergovernmental Panel on Climate Change (IPCC) (IPCC, 2001; McCarthy, et al., 2001) which can be defined as “the extent to which a natural or social system is susceptible to sustaining damage from climate change impacts, and is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity” (McCarthy, et al., 2001). The susceptibility of agriculture and livelihoods to climate change therefore can be presented as the aggregation of these composite components (Fritzsche, et al., 2014).

Meanwhile, it is crucial to understand that vulnerability is not a quantifiable phenomenon, it is instead a dynamic state which is the result of various interacting variables (Fritzsche, et al., 2014). As it cannot be measured or observed directly (Sherbinin, et al., 2017; Hamouda, et al., 2009), a number of indicators that are presumed to affect vulnerability are aggregated or combined to provide an indication or an index of vulnerability. Likewise, it is a relative scale that shows the spatial distribution of vulnerability within a specific location of analysis, which in our case is a water system. The aforementioned components or indicators are commonly used variables of agricultural vulnerability (Fritzsche, et al., 2014). Briefly, these indicators capture a region’s high biophysical and climate risks (Exposure), the resilience of the crop production systems (Sensitivity), and societal capacity to respond (Adaptive Capacity).

3.3. Vulnerability scenario in the BRB

The following section summarizes the results of the vulnerability indexing exercise. For comparison, it is important to note that index values should be interpreted as relative, rather than indicative, within the context of the analysis. The putative maps can be interpreted as a baseline showing the vulnerability of administrative regions, relative to each other, based on available climate and socioeconomic profiles.

The results suggest geographical patterns of climate-related vulnerability within the BRB (Figure 3). The degree of vulnerability of the administrative units between RCP2.6 and RCP8.5 projections was relatively identical for both scenarios. Overall percentages show that 42% of the towns in the BRB are relatively characterized by high to very high vulnerability for both RCP2.6 and RCP8.5, whereas, 35% are characterized by low to very low vulnerability under RCP2.6 against its counterpart 37%. Accordingly, 23% and 21% for RCP2.6 and RCP8.5, respectively, are relatively characterized as moderate. Both climatic simulations show the greatest hotspot of vulnerability occurs at the central and northwestern portions of the BRB. Specifically, the Thiris sub-basin (composed mainly of the towns of Bombon, Calabanga, Canaman, and Magarao) revealed to be significantly vulnerable to the impacts of climate change along with other parts of Ragay Hills (Balatan, Minalabac, Milaor, Pasacao, and San Fernando), Waras-Lalo (Baao) and the Libmanan-Pulantuna (Cabusao, Del Gallego, Lupi, and Ragay) sub-basins, due to loss in the climatic suitability, the presence of multiple natural hazards and also the relatively low adaptive capacity in these areas. In contrast, the entire Quinali sub-basin (composed of the towns of Camalig, Guinobatan, Libon, Ligao City, Oas, and Polangui) is suggested to cope relatively well with the challenges brought by climate change together with some parts of Naga-Yabo (Naga City), Pawili River (Pili), Waras-Lalo (Iriga City and Nabua), and the northeastern portion of the Libmanan-Pulantuna (Basud, Mercedes, San Lorenzo Ruiz, and Sipocot). The findings suggest three important observations which may need further empirical analysis. First, communities within the BRB greatly rely on agri-based enterprises (Figure S2) for food security that in essence, heavily depends on the climate, therefore, food production and changes in the climate are closely interlinked. Second, climate change can potentially disrupt the agri-food value chains (Lim-Camacho, et al., 2017) to which food security heavily depends. And third, climate change tends to impact communities disproportionately which further exacerbates poverty across the BRB. This vastly illustrates how the consequences of vulnerability will reverberate across highly vulnerable areas in the BRB if not addressed urgently and holistically.

To further analyze the trend of vulnerability across the BRB, we summarized the distribution of vulnerability index scores using a kernel density plot (Fig. 4). Data distribution for vulnerability in both climatic scenarios yielded a bimodal distribution with an average vulnerability category of moderate. However, the distribution suggests segregation of two distinct local maxima consisting of vulnerability scores that relatively fall under distinct ranges of high (> 0.625) and low (< 0.40) vulnerability categories, respectively. The dimensional nature of the data arises as a result of how climate change impacts every single administrative unit disproportionately. Adaptive capacity affects vulnerability by modulating exposure and sensitivity (Yohe and Tol, 2002; Adger et al., 2007). Considering that adaptive capacity has been attributed the highest importance in defining vulnerability in this study, contributing about 70% in the overall determination of the final index, we infer that administrative units or towns with increased adaptive capacity have the likelihood to cope with the effects of climate pressures thereby resulting to a relatively lower climate vulnerability, these gradually add up to form the global maximum (main peak). This is particularly true since these areas tend to have higher economic activity and availability of financial services, good access to health and education, and have more provision in terms of support services for agriculture. Whereas, towns that are disadvantaged in this aspect have a relatively high vulnerability, therefore, clusters to form the local maximum (lower peak). The graph, therefore, implies that although there exist a considerable number of towns that have relatively high coping chances, the majority of the towns are still vulnerable to the impacts of climate-related risks.

The geographical and density distributions of the specific indicators shown in Figure 5 further reveal each indicators' contribution to the overall vulnerability of the BRB. First, hazard exposure for the BRB was observed to be highest in some parts of the Thiris and southern portion of the Libmanan-Pulantuna sub-basins characterizing about 9% of the overall exposure of the BRB, primarily attributable to their location along the typhoon track found within the latitude range 14°N–16°N where most tropical cyclones typically landfall (Takagi & Esteban, 2016; Meigh & Bartlett, 2010) which encourages further risks brought about by storm surges and sea-level rise due to their immediate proximity to the seaboards, which in turn bring further flooding and occasional soil erosion in these areas. Moreover, adaptive capacity (AC) tends to be lowest in some portions of the Libmanan-Pulantuna and Ragay Hills sub-basins and very notable entirely in the Thiris sub-basin, additionally, some towns within the sub-basins of Pawili River, Waras-Lalo, and remaining parts of Ragay Hills are also characterized by low AC comprising about 58% of the overall adaptive capacity of the towns in the BRB. Finally, in terms of sensitivity, the averaged values of the five (5) agricultural commodities considered in this study suggest a decline in suitability of 9% for RCP2.6 and a drastic 21% for RCP8.5 concentrated mostly in the central portion of the BRB. Nevertheless, increased suitability by 42% for RCP2.6 and 21% for RCP8.5 is observed in the southern portion, specifically in Quinali and parts of the Waras-Lalo and Pawili River sub-basins. The remaining 49%-58%

of towns were observed to have no change in suitability under RCP2.6 and 8.5, respectively. The foregoing findings have numerous implications in the broader geographical context, as well as to many sectors, especially in the ASEAN where climate vulnerability is rooted in the region's unique geography (Øverland & Vakulchuk, 2017). These include taking advantage of a shared multi-scale stakeholders' experience in climate and disaster-resilient development to create a robust feedback system, thereby bolstering local agricultural resiliency. Additionally, increasing emphasis on proactive rather than reactive responses through robust improvement of respective adaptive capacities at each administrative level will reduce climate risks to acceptable levels. Assessments of vulnerability and risk are also integral in the overall scheme of addressing the impacts of climate change; not only do they inform decision making about the requisites for adaptive responses but they may also reveal whether mitigation efforts need to be strengthened because of the limits to adaptation. The challenge for policy now will be on how to mobilize developmental thrusts in both areas of disaster risk reduction and climate change adaptation, and stimulate conversation amongst concerned stakeholders and policymakers to attain a concerted measure to reduce anthropogenic footprints.

4. Limitations

Notwithstanding the seamless projection generated by the model, several limitations and caveats apply to our study. First, we acknowledged that the climate model outputs contain uncertainties due to factors such as lack of capability to represent the complexity of Earth's climate system, multiple emission scenarios, and unaccounted ecological and anthropogenic processes. However, despite such uncertainties, models remain a useful tool to forecast the impact of the future climate (Upgupta, et al., 2015). For future studies, we recommend the use of multiple modeling tools, since it can reduce the level of uncertainty (Alam and Starr, 2013). Second, although our model allows for identifying the sensitivity of the area, supplemental indicators like elevation, soil texture, and soil moisture were disregarded since most of the commodities grown in the BRB are strictly distributed throughout the Bicol Plain (see Supplemental Figure S1) where pedological properties (Carating, et al., 2014) remain relatively uniform. Finally, there still exists conceptual confusion on how vulnerability should be formally defined (Wolf, et al., 2013; Hinkel, 2011). The plurality of existing frameworks and possible interpretations even the selection of indicating variables are still contestable from a scientific point of view. Hinkel (2011) provided a framework where he decomposed the IPCC definition based on the definitions of the defining concepts given in the glossary of the Third Assessment Report (McCarthy et al., 2001) and presented concepts that are left undefined on a scientific purview. For simplicity, we kept the well-established definition of the IPCC to provide context to our readers suggesting that the definition be conventional. Further researches should be conducted to explicitly provide standardized terminologies to address these gaps.

5. Conclusions And Recommendations

With the growing challenges confronted by the local agriculture sector, well-placed policy and institutional strategies would significantly contribute to mitigating the consequences of the volatilities brought about by the current climate scenario. Additionally, tailor-made adaptation policies should be conceptualized since agricultural practices exist in a unique set of conditions relative to its ecological importance, current biophysical status, the history of management, stakeholder dynamics, local customs and traditions, local community-based institutions, and local economy (Upgupta, et al., 2015). In a broader sense, studying the multi-faceted aspects of climate change falls not only at the forefront of academia instead it transcends into a collaborative political and social duty. The information generated by vulnerability assessments is meant to cater further policy purposes such as updating of local climate change action plans (LCCAP) and advocating for common-sense climate solutions like clean energy promotion, climate-resilient agriculture practices, and regenerative agriculture among others. Assessing vulnerability thus has moved from being an academic exercise to being a political necessity (Hinkel, 2011).

Our findings can therefore be utilized especially by local government units (LGUs) to attract bilateral and multilateral support from various local and international stakeholders, prioritize and inform climate adaptation efforts that will minimize its impacts. Bolstering the adaptive capacity of vulnerable areas particularly in the Thiris sub-basin including some parts of Ragay Hills, Waras-Lalo, and the northwestern Libmanan-Pulantuna sub-basins, that is, improving education, income distribution, healthcare, pre- and post-disaster responses, institutional and administrative capacity-building (e.g. greater enforcement of regulations and norms, investment in human capital, decreasing corruption and inefficiencies), and increased accessibility to early warning systems and climate information services may help offset projected increases in vulnerability. It is also essential to upgrade water management facilities and retrofit existing infrastructures since it has been found out that saltwater intrusion and largescale flooding continue to persist in the area. Other sub-regions of the BRB with moderate to low vulnerability are recommended to practice gradual crop shifting in order to maintain the comparative advantage of the farmers. Policymakers may wish to build capacities for autonomous risk management and adaptation as part of social contracts to marginalized communities by providing livelihoods through strengthened public investment and support. Likewise, strategies to promote the resilience of ecosystems should also be given significant attention across the BRB since a wide range of ecosystem services provided by the basin are threatened by anthropogenic activities such as timber poaching, mangrove conversion, and over-fishing among others. These strategies should include but not be limited to the protection of existing natural forests, rehabilitation of degraded forest lands and protected areas, management of mangroves, wetlands, and coastal resources, and management of river easements, including resettlement planning and implementation.

In conclusion, our results highlighted specific regions of the Bicol River Basin where projected climate vulnerability will be expected to be widespread and robust, including the vulnerability perceptions of the local communities that are disproportionately influenced by the climate crisis. These findings have large implications on how agriculture will transform in the future into a climate-smart endeavor. We find that the model currently projects that majority of the towns in the north and central portions of the BRB will largely experience a decline in agricultural productivity, if, stringent adaptation and mitigation measures will not be strategized and established henceforth. The main idea is that, knowing the key drivers of vulnerability allows for more targeted action. For this, location-specific needs-based legislations must be established that shall help prioritize, protect, support, and incentivize the local agriculture sector most importantly its farmers — as they remain to be one of the country's economic backbone and pride of the working class.

Declarations

6. Supplementary Information This paper contains supplementary material.

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8. Ethical Approval Not applicable.

9. Consent to Participate Written informed consent was obtained from all individual participants included in the study.

10. Consent to Publish Not applicable.

11. Authors Contributions R.P. Laureta and R.R.H. Regalado designed the study. R.R.H. Regalado performed the analyses and data curation, with support from E.B. De La Cruz who also contributed materials/analysis tools. R.P. Laureta led the supervision and writing with input from all co-authors.

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13. Competing Interests The authors declare no competing interests.

14. Availability of data and materials Not applicable.

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Figures

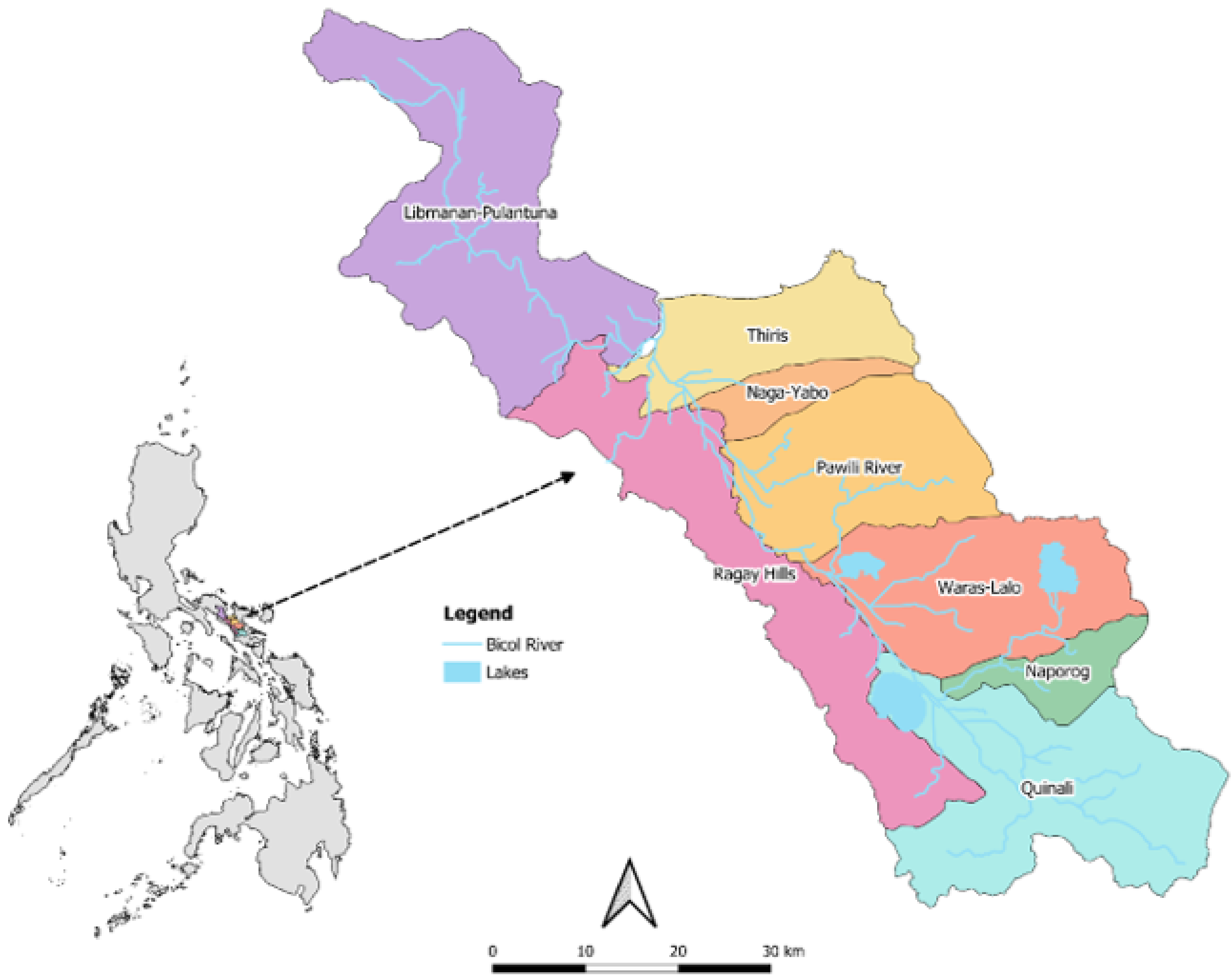

Figure 1

The Bicol River Basin area showing the eight major sub-basins that constitutes its general geographical characteristics.

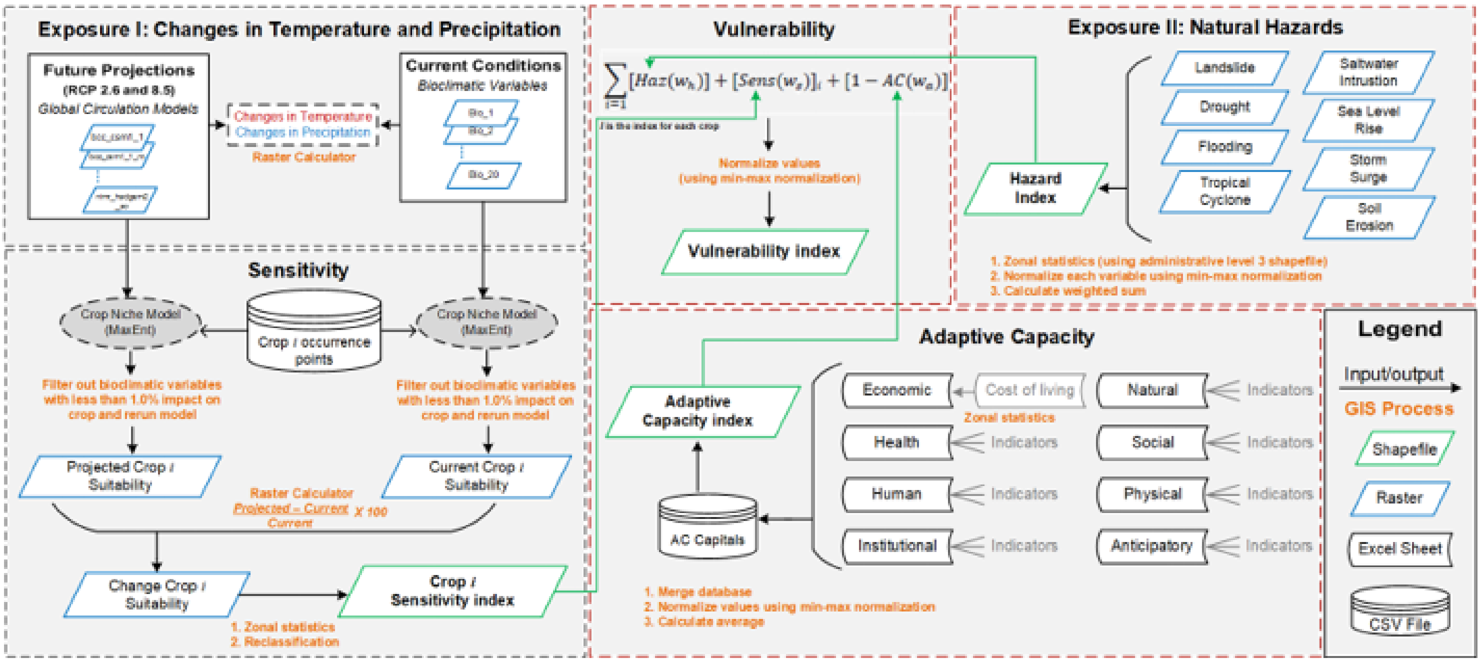

Figure 2

Climate Risk Vulnerability Assessment (CRVA) framework adopted from Parker et al. (2019) with modifications. Red dashed boxes indicate components containing authors' modifications from the adopted framework, briefly, different sets of indicators for exposure 2 and adaptive capacity were used, likewise, with the vulnerability equation. Arrows direct the flow of data from input to output of the GIS processes indicated in orange. Multivariable datasets compiled in excel sheet are represented by horizontal open cylinders while raster spatial data by parallelograms. Green parallelograms indicate the output of the GIS process which are formatted into shapefile datasets. Finally, vertical closed cylinders are comma delimited value (CSV) file which acts as the database.

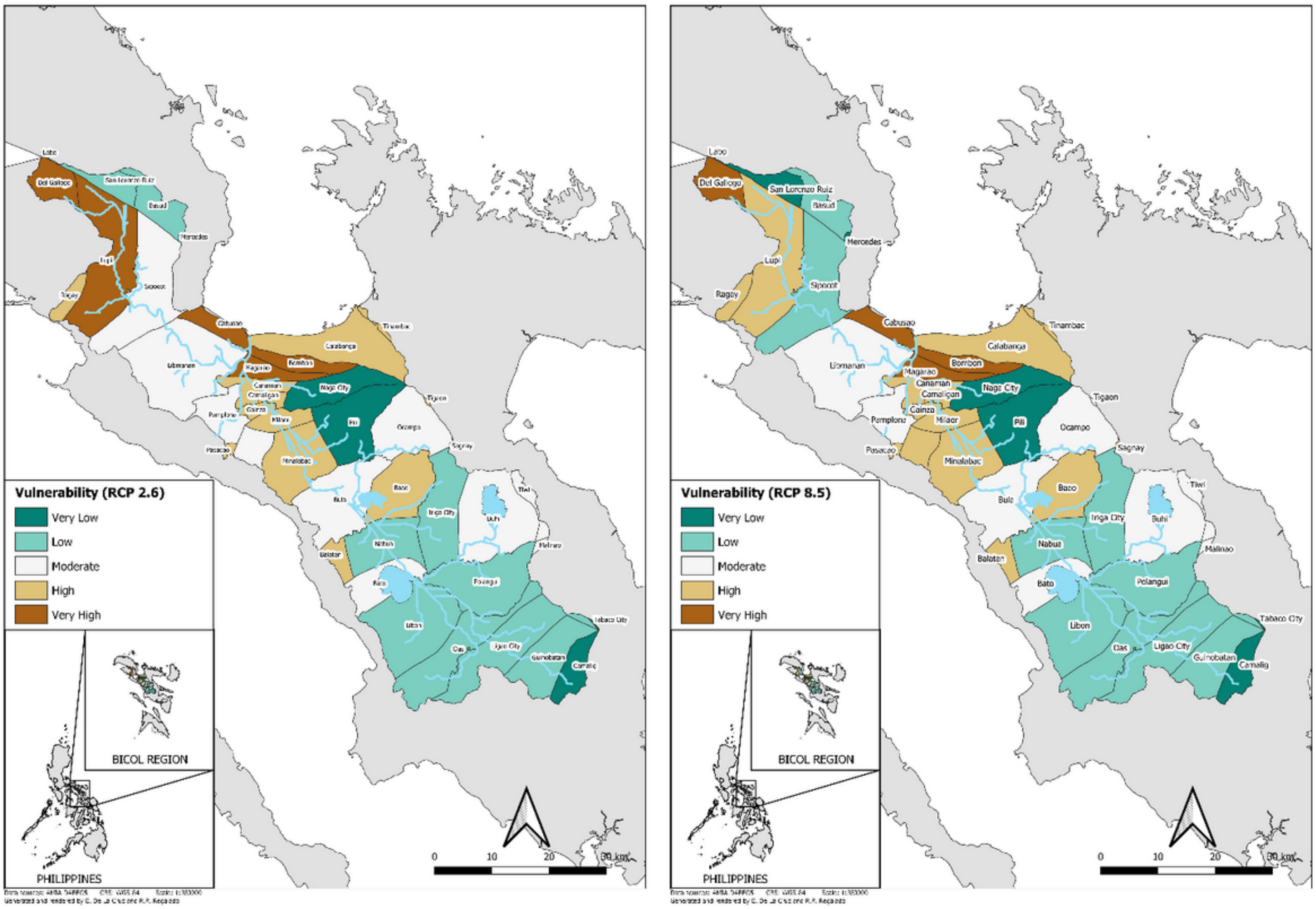

Figure 3

Climate vulnerability scenario (2050) of the Bicol River Basin under RCP2.6 and RCP8.5 climatic projections, calculated as a function of exposure to natural hazards, sensitivity of selected crops to climate change and adaptive capacity of the population.

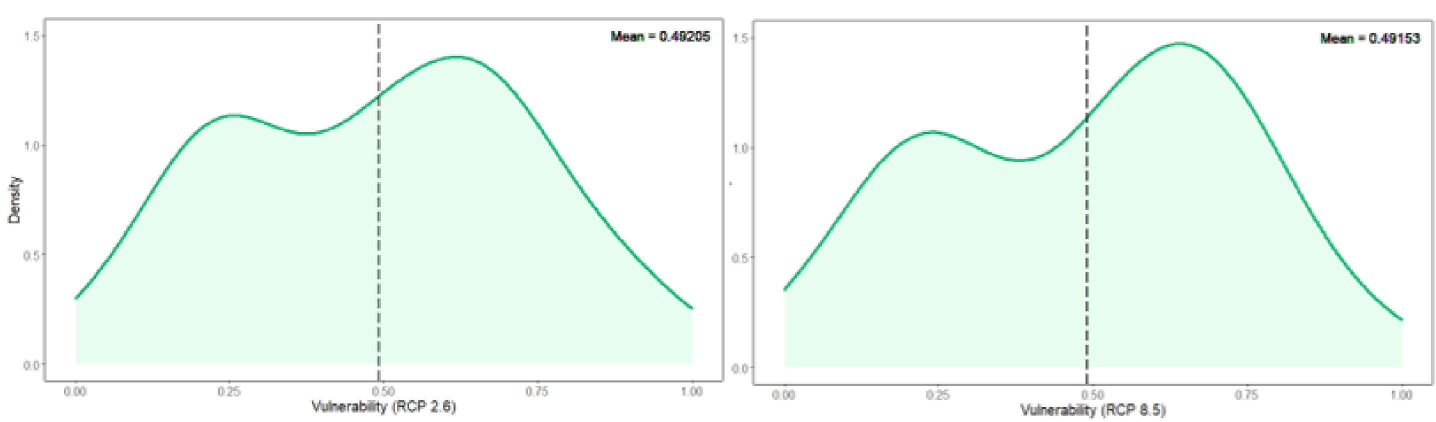

Figure 4

Kernel density plot showing summarized distribution of vulnerability index scores across administrative units for both RCP2.6 and RCP8.5 climatic projections.

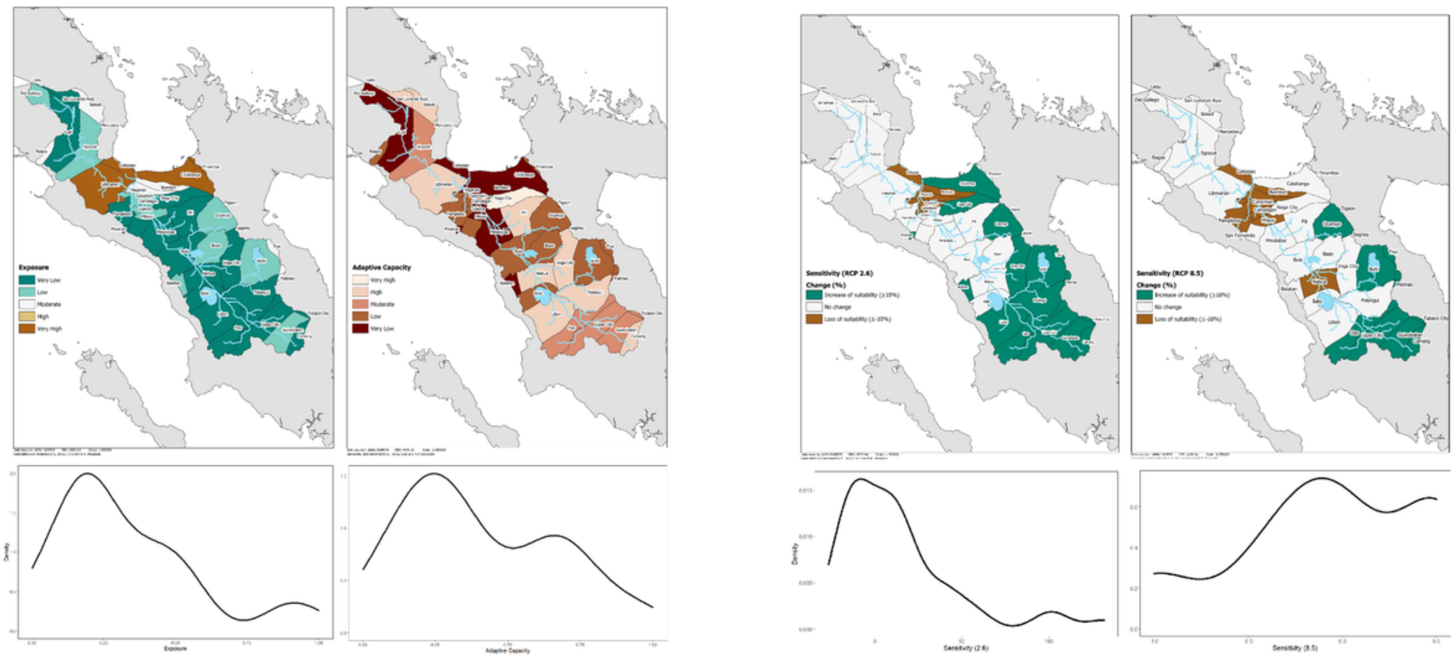

Figure 5

Vulnerability component maps and kernel density plots showing the distribution of the vulnerability components: exposure (left) and adaptive capacity (right). (cont). Vulnerability component maps and kernel density plots showing the distribution of the vulnerability components: sensitivity under RCP2.6 (left) and sensitivity under RCP8.5 (right).

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- SupportingMaterial.docx