



Exposure of the Population of Mindanao to Combined Natural and Anthropogenic Environmental Stressors

Hernan G. Pantolla* and Alex C. Gonzaga

Received : January 11, 2024

Revised : April 18, 2024

Accepted : April 30, 2024

Online : May 19, 2024

Abstract

In 2019, El Niño Southern Oscillation (ENSO) episodes in conjunction with climate change resulted in significant adverse impacts, particularly on developing nations. The year 2019 ranked among the top three warmest years since the mid-1800s. This paper aims to comprehensively analyze the El Niño period and the worsening climate trends observed in Mindanao, Philippines, during that year. The application of spatial analysis techniques revealed the existence of poverty hotspots characterized by below-average precipitation and enduring episodes of dangerous levels of heat index. The study documented instances of crop destruction and farmers' resulting problems. The application of multivariate clustering analysis revealed a significant association between urbanization and elevated mortality rates in climate-sensitive diseases. This finding suggests that the degree of urbanization has an apparent impact on regional mortality rates, ranging from modest to substantial increases. The findings underscore the necessity of implementing early warning systems and developing and implementing mitigation and adaptation methods. This is particularly crucial in sectors susceptible to adverse effects, such as agriculture and healthcare, where the immediate consequences are already observable.

Keywords: Climate Change, Data Visualization, El Niño, Food Security, Human Health, Mindanao

1. INTRODUCTION

The year 2019 was one of the top three warmest years since records began in the mid-to-late 1800s. Only 2016 and, for specific datasets, 2015 were warmer than 2019. In addition, since the mid-1800s, all years after 2013 have been warmer than all previous ones [1]. A weak El Niño was also present in the tropical Pacific Ocean at the start of the year [1]. The natural phenomena of El Niño and La Niña represent cyclical environmental disturbances with significant global implications. Initially coined to describe water warming along Ecuadorian and Peruvian coasts disrupting local fishing economies, El Niño now refers to basin-wide warming in the eastern tropical Pacific Ocean, associated with the Southern Oscillation's pressure patterns [2]. El Niño events, part of the El Niño Southern Oscillation

(ENSO) cycle, profoundly impact wind, rainfall, and sea surface temperature patterns in the tropical Pacific, influencing global climates through teleconnections.

La Niña, the cold phase of ENSO, contrasts with El Niño's warming effects. The United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP) recognizes ENSO as a significant global climate phenomenon affecting human cultures and ecosystems via disrupted rainfall and temperature patterns. El Niño and La Niña mark opposing ends of the ENSO cycle. El Niño events occur every two to seven years when equatorial Pacific Ocean temperatures rise, and trade winds weaken [3]. The 2015–2016 El Niño severely impacted over 60 million people globally, causing temperature increases, reduced rainfall leading to drought, and altered tropical cyclone patterns. In Asia and the Pacific, it led to crop destruction, livestock deaths, water source depletion, severe flooding, food insecurity, disease outbreaks, and migration [3].

In early 2019, the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA) noted abnormal sea surface temperature (SST) increases in the central and eastern equatorial Pacific, signaling a potential El Niño episode. Despite weak El Niño effects projections, PAGASA warned of below-average

Publisher's Note:

Pandawa Institute stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.



Copyright:

© 2024 by the author(s).

Licensee Pandawa Institute, Metro, Indonesia. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

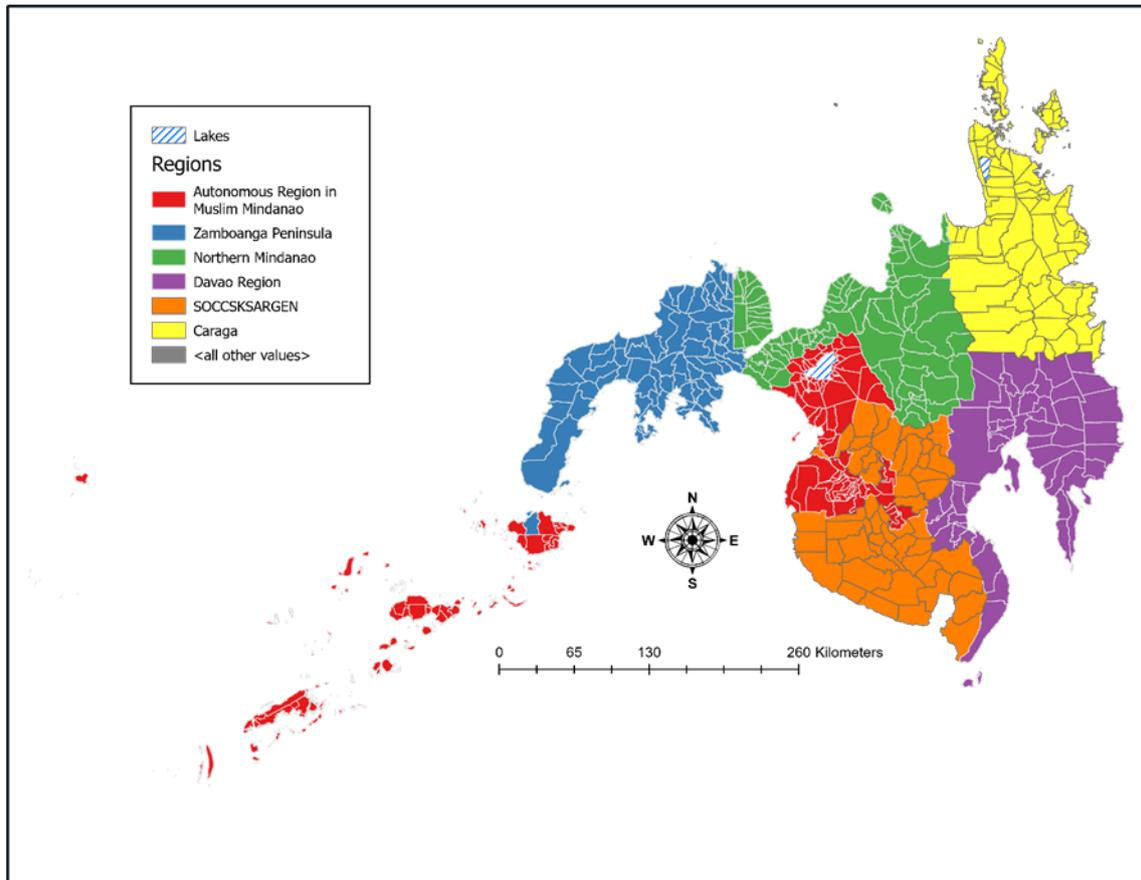


Figure 1. Map of Mindanao by administrative region.

rainfall in various regions and anticipated elevated surface temperatures. A series of advisories culminated in August 2019, stating that El Niño had concluded. The final report highlighted below-average rainfall in southern and western regions [4]. This cyclical natural phenomenon's widespread climatic repercussions underscore the need for global awareness and adaptive strategies to mitigate its impact on vulnerable communities.

Climate change, as defined by the United Nations Framework Convention on Climate Change (UNFCCC), refers to long-term variations in weather patterns and temperatures. While natural causes contribute to these changes, human activities, mainly burning fossil fuels like coal, gas, and oil, have been identified as the primary driver [5]. According to the World Bank (WB), climate change's repercussions extend beyond environmental concerns, impacting global social inequality and threatening poverty eradication efforts [6]. Vulnerable populations, particularly in developing nations, are at risk of climate-related shocks, including income and property loss, the

spread of diseases during extreme weather events, degraded crop production, and increased food prices [6]. Furthermore, climate change can push individuals, initially above the poverty threshold, into impoverished conditions through the destruction of businesses, loss of livestock, and health implications resulting from environmental changes [6].

As human activities release more greenhouse gases, trapping heat in the atmosphere, temperatures are projected to rise. This increase in temperature is expected to lead to higher morbidity and mortality rates, especially among populations unprepared for extreme heat events. Vulnerable groups, such as the poor, children, the elderly, and those with preexisting health conditions, face heightened risks from increased exposure to extreme heat [7][8]. Meteorological parameters, including rainfall, temperature, and heat, are closely linked to dietary effects, resulting in child stunting, undernutrition, and malnutrition. Weather patterns' variations, particularly temperature increases and rainfall decreases, directly impact crop output and food

security [9]. The WB emphasizes that poverty reduction cannot be achieved without addressing the impact of climate change on poor populations and implementing strategies for mitigation [6].

Climate change-related environmental pressures and shocks hinder poverty reduction by influencing natural disasters, health outcomes, agricultural losses, and food costs. The poor are disproportionately affected due to their higher susceptibility to climatic shocks, compounded by limited resources and support systems. Unfortunately, climate change is expected to exacerbate these challenges, making sustainable poverty alleviation more difficult [6]. According to the Food Research & Action Center (FRAC), the healthcare community recognizes that social determinants of health, such as environmental conditions, play a more significant role in shaping health outcomes than medical care. Food insecurity and poverty are linked to severe and costly health issues, including inadequate income, prioritization challenges, and stress. Individuals facing food insecurity or poverty encounter obstacles in maintaining good health, accessing nutrient-dense diets, and managing chronic diseases [10].

Research indicates that individuals classified as poor or near poverty experience worse health outcomes and encounter more difficulties accessing healthcare compared to those not facing economic hardship [10]-[13]. Childhood poverty and socioeconomic inequities have long-lasting effects on health, leading to chronic illnesses, poor mental health, and adverse health habits in adulthood. Child poverty is also associated with increased healthcare expenditures, lower educational achievement, reduced earning capacity in adulthood, and a higher likelihood of poverty in old age [10]. Poor adults are more prone to health problems, including diabetes, stroke, heart disease, and premature mortality [10][14]-[16]. The complex interplay between climate change, poverty, and health underscores the urgent need for comprehensive strategies addressing environmental and social determinants to achieve sustainable development and well-being for all.

The Intergovernmental Panel on Climate Change (IPCC) asserts with high confidence that climate change has substantial implications for mental health and the physical well-being of global

populations [17]. The impacts of climate change are far-reaching, affecting human and natural systems, including social and economic conditions, with consequential effects on health. Across regions experiencing elevated temperatures, there is a consistent pattern of increased morbidity and mortality. Furthermore, the prevalence and spread of vector-borne diseases have risen, with instances of an augmented number of disease vectors [17].

Projections from climate change simulations indicate a future characterized by more substantial and frequent rainfall events in most parts of the world [17][18]. Asia is particularly vulnerable to flooding, and without adequate adaptive measures, health losses resulting from floods and storms are expected to escalate in this century [17][19]. Isolated and rural populations face heightened susceptibility to illness due to limited access to healthcare and increased economic and social constraints [17][18]. Additionally, communities already exposed to diseases transmitted by vectors are particularly vulnerable to changing climatic conditions, necessitating effective mechanisms for disease control [17][20][21].

Studies highlight the meteorological elements, including rainfall, temperature, humidity, and wind, as contributors to the proliferation of vector-borne diseases such as dengue and malaria. However, the association between these variables and disease spread varies, influenced by factors like seasonality, location, and interactions with other climatic parameters [9]. Urban populations also face heightened health risks due to heat waves compounded by the urban heat island effect [17][22][23]. Geographical location is crucial in determining the magnitude of climate-related health risks [24]. Outdoor workers in nations experiencing the hottest months are more severely impacted, with potential consequences for their health [17][25]. In regions with insufficient rainfall, malnutrition becomes a significant threat to farming-dependent populations in rural areas, although local solutions such as irrigation systems can mitigate this concern [17][26].

The physiological effects of severe heat are well-documented in scientific literature, with experimental research suggesting an increased risk of injury in warm working environments [27]. Heat-related impacts include heatstroke, heat exhaustion,

and the exacerbation of chronic diseases. Dehydration and heat stress can worsen existing renal disorders, and increased ozone levels due to heat may exacerbate respiratory and cardiovascular problems [28]. Over 50% of non-household labor hours globally are outdoors, primarily in construction and agriculture [17]. Workers in these sectors are exposed to high temperatures, increasing the risk of heat-related illnesses. Lack of shelter and water further amplifies the dangers of heat exhaustion and heat stroke, particularly in tropical and developing nations. Even indoor workers are not immune, as inadequate workplace temperature regulation can lead to heat stress. In industrialized countries like the United States, some workers experience heat stress, impacting productivity as longer breaks become necessary to avoid health risks [29]-[31].

According to the literature, it was determined that high, low, and diurnal temperatures are associated with both direct and indirect causes of mortality [9]. It has been established that a strong

correlation exists between heat, heat waves, and mortality as the direct cause. Heat and heat waves are also connected to heatstroke, stroke, respiratory, and cardiovascular outcomes, particularly in rural locations, young populations, and aging populations. The link between heat and child mortality is ambiguous, particularly in some geographical regions, whereas the association between heat-related mortality and the intensity of heat waves was stronger. Lastly, despite the paucity of research, low temperatures were associated with respiratory, cardiovascular, and cerebrovascular mortality, as well as stroke [32]. Climate change, exacerbated by warmer weather and El Niño/La Niña episodes, is intensifying the frequency of droughts in the Philippines [2]. While the direct correlations between recent El Niño/La Niña events and climate change are inconclusive, their combination with climate change has catastrophic consequences [2][33]. Future El Niño strengths and types remain undetermined due to climate change, but their impact on local temperature and rainfall

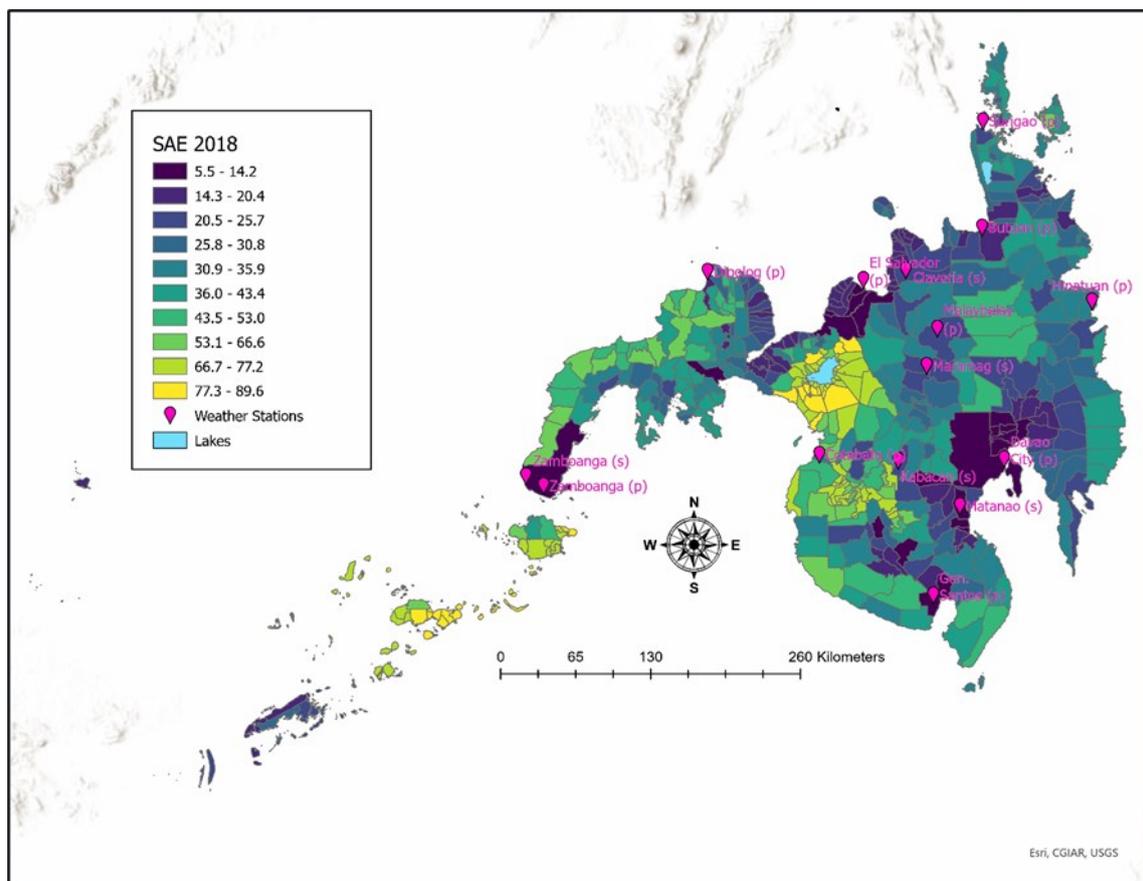


Figure 2. Choropleth map showing SAE of poverty incidence in Mindanao by municipality and city, as well as locations of the weather stations.

patterns is expected to intensify [3].

These climate events contribute to poverty by reducing agricultural productivity and increasing the cost of essential foods for impoverished households. Low-income groups, particularly urban wage-labor-dependent strata, are highly sensitive to food price increases, leading to decreased overall consumption and pushing them below the poverty line [2]. The impact on impoverished farmers is more severe due to their limited income sources. Food insecurity and malnutrition persist as significant issues in the Philippines, especially in rural areas with high poverty levels. The high cost of food, particularly rice, exacerbates these issues, contributing to hunger and malnutrition. The World Risk Index ranks the Philippines as the second most at risk from climate change effects, further emphasizing the severity of the situation [34]. Climate variations amplify vulnerability in agriculture, food production, and vulnerable populations. The effects of climate change are expected to worsen beyond 2050, with agriculture significantly contributing to poverty [34]. Increased rainfall positively impacts agricultural revenues but negatively affects food security, while extreme temperature events increase the risk of malnutrition, particularly in agriculturally dependent households [34].

The Philippines anticipates a more significant impact on rainfall variability than temperature rise due to climate change [2][35]. Persistently recorded extremely variable rainfall patterns adversely affect the agricultural industry, particularly rice, which is highly vulnerable to environmental stress. Extreme rainfall after seedling planting can kill rice plants due to heat or water stress [2][36]. Corn, a vital crop in the Philippines, is affected by water stress, a significant yield-reducing factor exacerbated by climate change. Water stress poses challenges to crop adaptation, necessitating site-specific studies for adaptation and mitigation, drought-resistant crops, and enhanced monitoring systems [2][37] [38]. The Philippines, facing widespread infectious diseases, has a vulnerable public health system exacerbated by climatic extremes. Climate change increases the vulnerability of the populace to climate-sensitive diseases, including vector-borne illnesses and heat-related diseases. Dengue, sensitive to rainfall, temperature, and humidity, is a

notable example. Climate change significantly impacts the prevalence and severity of various infectious diseases, affecting liver diseases and the emergence of new infectious agents [2].

Cross-disciplinary studies and collaboration with public health decision-makers are essential for health protection. Focus areas include improved vulnerability and adaptation assessments for vulnerable populations, quantitative estimations of health adaptation measures' effectiveness, and surveillance systems linking climate, health, and economic impact data for early warning scenarios [2][39]. As introduced briefly, ENSO events that periodically and naturally occur and climate change are mainly attributed to anthropogenic activities, cause agricultural damages and adverse health outcomes, among others. This study thus intends to provide a deeper investigation into the latest year where an ENSO event occurred about the prevailing and worsening changes in climatic patterns. Remarkably, this paper will provide some information based on available data on the effects of El Niño coupled with the changing climate in 2019 for a selected geographical landmass in the Philippines.

Geostatistical analyses and data visualizations in various forms shall be provided. Selected adverse effects in the agriculture and health sectors that were apparent in the year 2019 shall be presented as well. By doing so, this paper intends to contribute to the global and local calls of the United Nations (UN) via the Sustainable Development Goals (SDG) to address some critical concerns (UN accessed 2022). The findings could contribute to the clamors for the SDG, namely (a) no poverty, (b) zero hunger, (c) good health and well-being, and (d) climate action, which are evidence-based. This paper will also highlight how critical early warning systems, adaptation, and mitigation practices [40]. Moreover, given the recurrence of ENSO events, this study could provide apposite contributions to the existing research gaps on the effects of the changing climate on agriculture and human health in specific locations.

The southern portion of the Philippines, where the Mindanao Group of Islands, or simply Mindanao, is located, is the study setting of this paper. Mindanao, as described by the Mindanao Development Authority (MinDA), is a beautiful

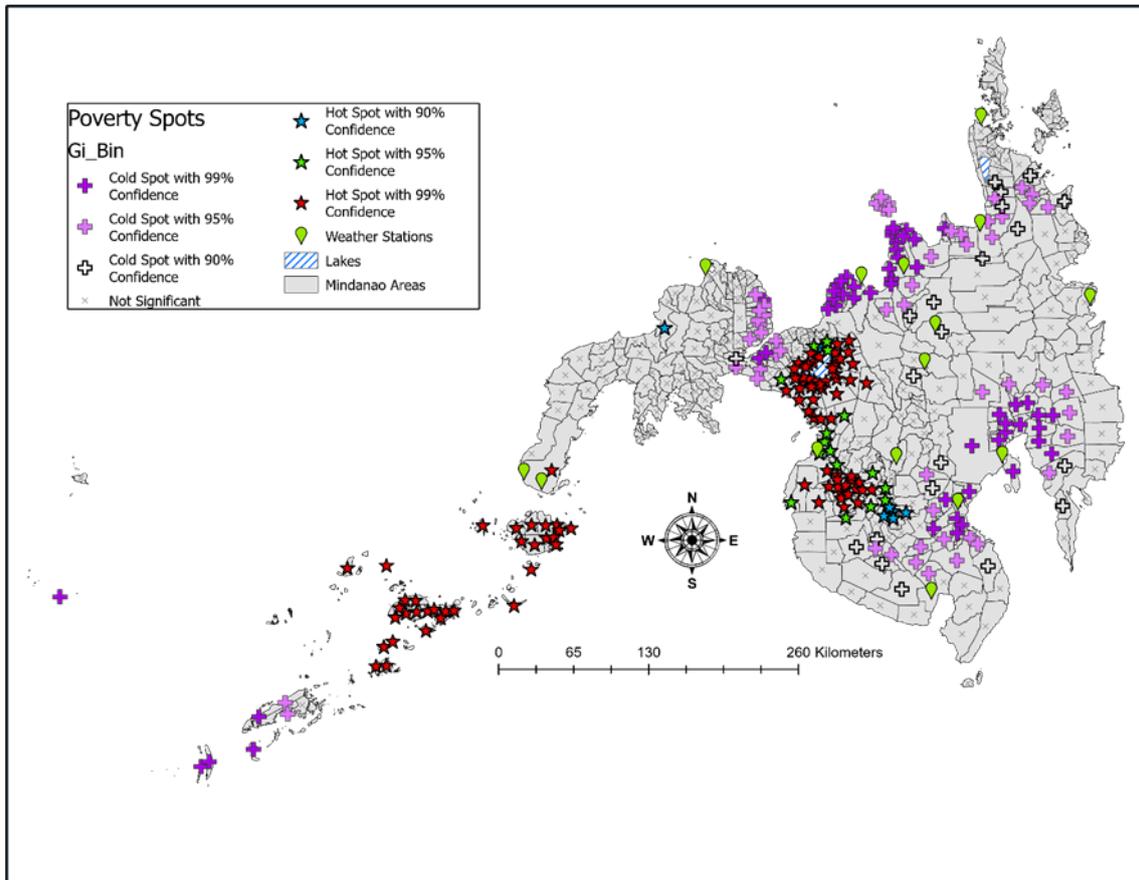


Figure 3. Hot spots and cold spots of poverty incidence in Mindanao.

place of peaceful and prosperous communities, with lands and waters offering abundant natural resources and rich cultures. It benefits from vast plantations, enterprises, and resource-based economic activities [41]. However, it is also known for its regions of extreme poverty, stark inequality, advertent destruction and depletion of natural resources, and violent conflict. The contradictions in the features of Mindanao are so pronounced, and the possibilities for reconciling these extremes so elusive that any effort to conduct another round of analysis and planning is burdened by a history of very mixed outcomes [41].

The damage left behind is frequently difficult for impoverished farming families to recover. During the 2015 to 2016 El Niño, Filipino farmers lost 1.5 million tons of crops, and over 400 thousand people needed assistance to recover. Mindanao experienced extensive damages and losses of USD 325 million, according to the Food and Agriculture Organization of the UN [42]. The frequency and severity of natural disasters are growing due to climate change. Temperatures have also risen,

making extreme heat more prevalent across the nation. Such alterations make it more difficult for the Philippine government to protect its citizens from shocks, especially the most vulnerable members [42]. Based on the Small Area Estimation (SAE) of poverty of the Philippine Statistics Authority (PSA) at the municipal and city levels, Mindanao has the poorest households in the country [43]. The PSA publishes the SAE every three years. The first issue was for 2000; the most recent issue was published on December 15, 2021, for 2018. Consistently, estimations indicate that Mindanao is home to some of the poorest municipal and city households. Figure 1 shows the map of Mindanao by administrative regions. The regions, namely, are (1) the Autonomous Region of Muslim Mindanao (ARMM) which can be interchangeably referred to as Bangsamoro Autonomous Region in Muslim Mindanao (BARMM), (2) the Caraga Administrative Region (Caraga), (3) the Davao Region, (4) Northern Mindanao, (5) South Cotabato, Cotabato, Sultan Kudarat, Sarangani and General Santos (SOCCSKSARGEN), and (6)

Zamboanga Peninsula. These regions are composed of 27 provinces geographically disaggregated further into cities and municipalities.

2. MATERIALS AND METHODS

Primarily, the study would generate a geographic information system (GIS) that visually represents possible municipalities and cities in Mindanao that could be statistically recognized as poverty hot spots or cold spots. The spot map will be superimposed on maps with spatial interpolations of environmental stressors, specifically heat and water stress. The heat stress maps shall be displayed using interpolated datasets of a converted heat index that accounts for the contributions of relative humidity to prevalent temperatures. On the other hand, the water stress anticipated to result from a lack of received rainfall will be interpolated using rainfall data sets. The two separate GIS are expected to show the exposure of the populations in Mindanao to (a) less than normal rainfall amounts and (b) experienced higher heat indices, which were caused by the El Niño phenomenon and warming environment due to climate change. The study will also provide an overview of the damage to agriculture, particularly in the major crops and farmers in the selected setting.

2.1. Sources of Data

The year 2019, an El Niño year, was chosen to illustrate graphically and quantitatively the variations in environmental stresses by seasonal quarters, given the climatic variabilities experienced amidst the changing climate. The daily weather data from ten PAGASA stations and five Smarter Approaches to Reinvigorate Agriculture as an Industry in the Philippines (Project SARAI) agrometeorological stations shall be used for the weather data, namely rainfall [in millimeters (mm)], maximum temperature [in degrees Celsius (°C)], and relative humidity [in percent (%)] [43]. Quarterly seasonal maps of 2019 shall be shown.

2.2. Procedures

To determine the spots (hot or cold), the 2018 cities and municipalities SAE of poverty from the PSA shall be utilized. This analysis will be conducted using ArcGIS Pro 3.0.1. The required

data management was performed to adapt the daily data to match the seasonal quarterly grouping of months that the PAGASA uses as the standard. The first quarter consists of December 2018, January, and February 2019 (DJF). The same approach was used for the second quarter consisting of March, April, and May (MAM), the third quarter made up of June, July, and August (JJA), and the fourth quarter comprised of September, October, and November (SON) of 2019. Only the total amount of rainfall will be utilized as an indicator of water stress. In contrast, the maximum temperature and relative humidity will be used to calculate the converted *heat index* as the heat stress indicators. The heat index data was generated using the online converter from the National Weather Service (NWS) website of the National Oceanic and Atmospheric Administration [44].

A GIS integrates multiple geographical data from the real world. It is a scientific instrument for processing, collecting, and analyzing data. It has several uses, including those relating to humans, mainly statistical and epidemiological data, such as the geographical spread of illness [45]. As a result of the restricted number of weather stations, geostatistical interpolation will be performed. In geographic statistics, this method is typically known as kriging. The term *kriging* is an interpolation technique that, at its most basic level, converts partial observations of a spatial feature into predictions of such features at unobserved locations [46].

Statistically establishing the potential clustering of poverty incidence hot spots or cold spots is essential. Therefore, the analysis for hot spots and cold places will be performed first. Afterward, spatially interpolated images of the anticipated lack of rainfall and the heat index shall be presented. Wang et al. define the heat index as the excessively high temperature multiplied by the relative humidity that reduces the ability of the human body to self-cool [47]. In other words, the heat index, also known as the apparent temperature, describes how humans feel when relative humidity is added to the actual temperature [48]. Figure 2 displays the map of the study area, the incidence of poverty, and the locations of all weather stations.

Figure 2 depicts the archipelagic features and meteorological station locations of Mindanao. The

"(p)" and "(s)" in the weather stations represent PAGASA and Project SARAI, respectively. The 10-level natural-break choropleth map also reveals that the areas with the lowest incidence of poverty among families range from 5.5% to 14.2%. In comparison, the areas with the highest incidence of poverty among households range from 77.3% to 89.6%. In addition, most ARMM areas generally have a higher incidence of poverty than the other regions.

2.3. Choice Spatial Interpolation Method

To estimate the spatial distribution of a feature of interest (say poverty incidence) based on the semi-variogram theory, geostatistical approaches such as Ordinary Kriging and its variations use the spatial correlation structure among observed data [49]-[51]. To obtain appropriate results using traditional kriging methods, the semi-variogram parameters of the model must be manually adjusted in GIS [20] [51]. It represents the geographic variability in a regionalized variable.

There are numerous kriging procedures, some of which were developed for specific applications. However, this study will concentrate on using Empirical Bayesian Kriging (EBK). EBK is a spatial interpolation method that requires minimal interactive modeling and is characterized by being robust and straightforward. This geostatistical interpolation technique enables automated kriging processing. As a result, the EBK calculates the parameters automatically utilizing simulation and sub-setting rather than manually tweaking the settings to provide correct and processed results. The primary advantage of EBK over other kriging techniques is its ability to correct mistakes caused by the estimate of the underlying semi-variogram [52]. In addition, EBK can forecast the errors associated with the generated predicted values and the values of unsampled regions. Each variogram parameter is simulated voluminous times. Using the simulated data, the outcomes of the variogram models are then calculated. This procedure renders EBK prediction more precise than conventional

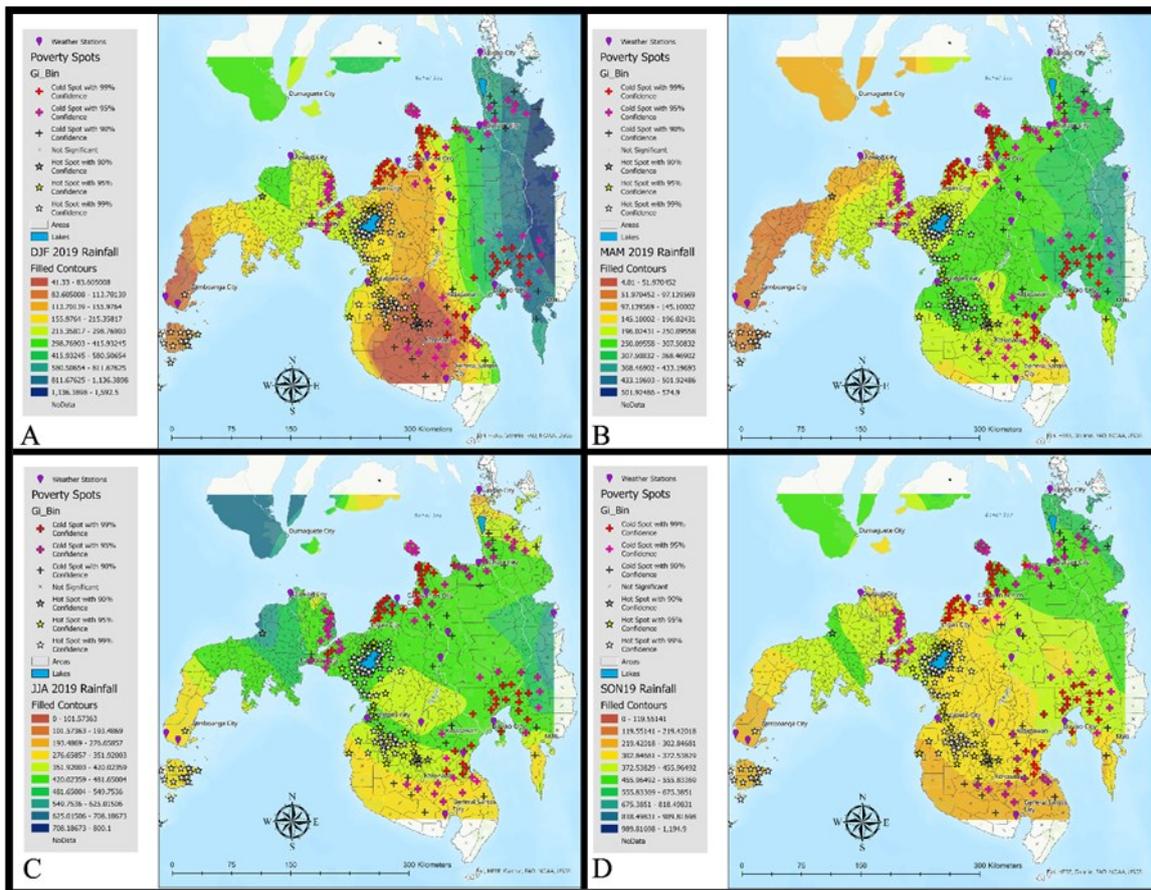


Figure 4. EBK of the amount of rainfall received in the coverable areas of Mindanao with poverty incidence hot spots and cold spots of Mindanao for 2019 quarters.

kriging methods [51][53]. In addition, EBK has been empirically demonstrated to generate accurate predictions for nonstationary and non-Gaussian data, including situations in which data variations across space are not smooth, making it a reliable automatic interpolation method [51][54]. Due to the (a) restricted number of weather stations and (b) large geographical area, it may be difficult for other kriging methods to provide accurate forecasts. The EBK will be applied, hence. The EBK framework is provided as follows [51].

$$\Pi_p > z_p(\chi_0) = \sum_{l=1}^{L^*} w_l i_p(\chi_l) + \sum_{l=1}^{L^*} s_l^v \Psi(\chi_l). \tag{1}$$

In (1), Π is the interpolated value while P is the parameter and is the critical level of such parameter. Any locational point, which are weather stations for this study, is represented by χ_l and the total number of locations is denoted by L^* . The weight of the known location is w_l while i_p factor could be 0 if it is higher than, or 1 if lower than z_p . The kriging weight represented by s_l^v which is estimated based on the cross-variogram between components in (2) and $i_p(\chi, P)$ in (3) is given below.

$$\Psi(\chi) = \rho/l, \text{ and} \tag{2}$$

$$i_p(\chi, P) = \begin{cases} 0 & \text{if } \chi(\chi) \geq z_p \\ 1 & \text{if } \chi(\chi) < z_p \end{cases}. \tag{3}$$

The ρ component in (2) stands for the ρ^{th} order statistics for a parameter measured at the χ location [51][53]. This simplifies the approach for estimating an unknown sample [53][55]. Initial estimation of a semi-variogram from known data is followed by simulation of a new value derived from the calculated variogram. Next, a new semi-variogram is re-estimated using the newly simulated data, with the new weight of the variogram computed according to Bayes' Rule [53][55].

2.4. Statistical Analysis

Probable hot spots and cold spots of poor households shall be empirically identified if significant. The spots shall also be presented visually via separate pieces of GIS. In mapping the possible hot spots and cold spots of poverty in

Mindanao, the Getis-Ord G_i^* will be applied via the application of Optimized Hot Spot Analysis in ArcGIS Pro 3.0.1. Notably, the Getis-Ord method measures how highly or lowly concentrated a feature is in each area and thus identifies the area as a hot spot or cold spot [56][57]. To simplify, and in the context of this part of the study, aggregated high values of poverty incidence indicate that G_i^* is a hot spot, whereas low values of aggregated poverty incidence denote a G_i^* that is a cold spot. Furthermore, when the observed G_i^* values surpass the expected values, a hot spot is pinpointed, while a cold spot is identified if an observed G_i^* falls short of the expected values [58]. The G_i^* statistic is a normalized value given Eq. 4 [56][57].

$$G_i^* = \frac{\sum_{j=1}^{A^*} m_{i,j} c_j - \bar{C} \sum_{j=1}^{A^*} m_{i,j}}{S_c \sqrt{\frac{\left(A^* \sum_{j=1}^{A^*} m_{i,j}^2 \right) - \left(\sum_{j=1}^{A^*} m_{i,j} \right)^2}{A^* - 1}}} \tag{4}$$

Now for this study, c_j is the poverty per area with its corresponding spatial weight given by $m_{i,j}$ between i and j , and A^* aggregated number of areas. The mean value poverty incidence is denoted by \bar{C} given by $\bar{C} = \sum_{j=1}^{A^*} c_j / A^*$ and the standard deviation indicated by (5)

$$S_c \text{ is given by } S_c = \sqrt{\left(\sum_{j=1}^{A^*} c_j^2 / A^* \right) - \bar{C}^2}. \tag{5}$$

2.5. Data Visualizations

Graphs showing the damage to major crops and farmers shall be provided. Visual comparisons of mortalities to various outcomes shall be given as well. Data from the year 2018 against the year 2019 shall be presented for simplified quantitative comparisons. The data visualizations will be based on the latest available data or annual aggregates from the concerned government agencies.

3. RESULTS AND DISCUSSIONS

The Getis-Ord G_i^* was applied, and Figure 3 shows the generated GIS. As shown, hot spots and cold spots of poverty incidence are statistically proven with varying levels of confidence. Mindanao's northern and southern parts are

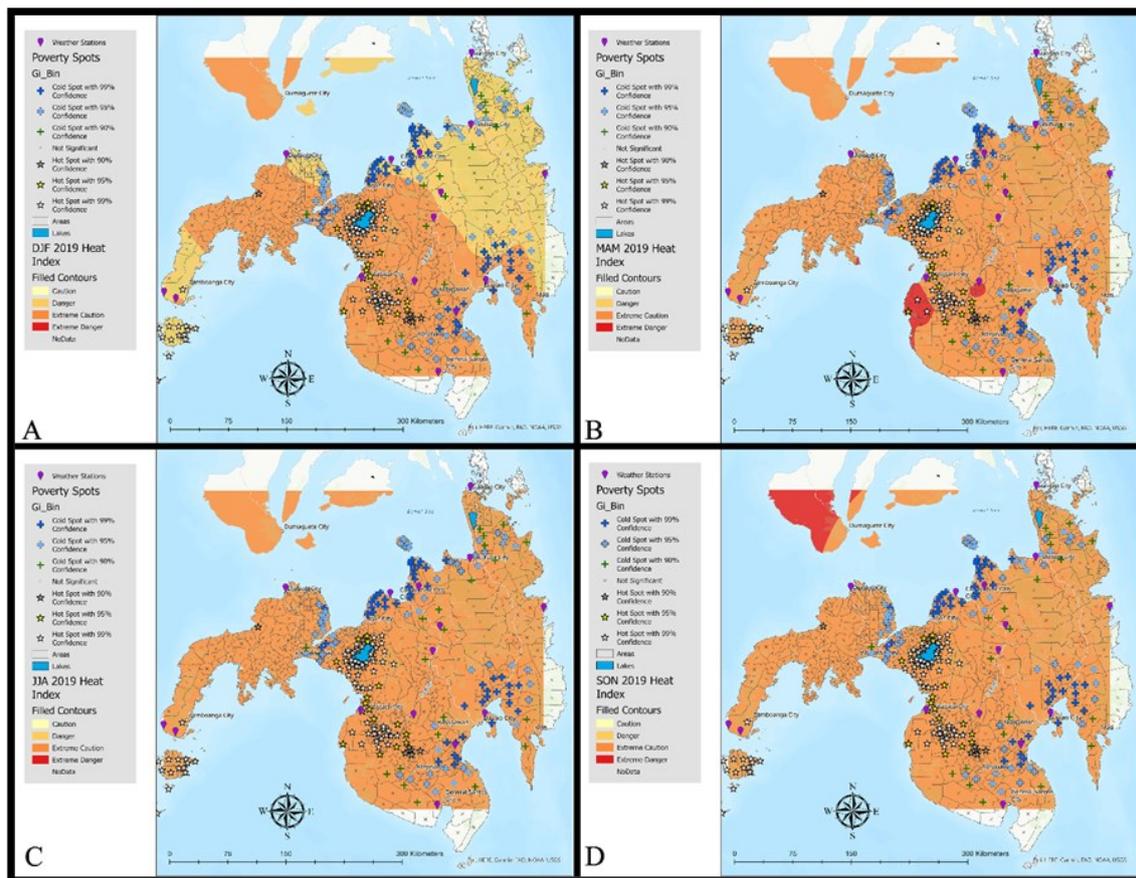


Figure 5. EBK of mean heat index in the coverable areas of Mindanao with poverty incidence hot spots and cold spots of Mindanao for 2019 quarters.

generally the cold spots of poverty incidence. On the other hand, most of the municipalities and cities of BARMM, aside from those in the province of Tawi-Tawi, as visualized in Figure 1, are identified as hot spots of poverty incidence, which comes expectedly based on Figure 2.

The EBK maps were then constructed to depict the extent of exposure to environmental stressors among the populations in Mindanao. Figures 4 and 5 show the quarterly spatially interpolated amount of quarterly rainfall and experienced heat index for 2019 in succession. The ranges of rainfall data depend on the data available, and they are presented on a 10-level natural break scale in Figure 4. On the other hand, the mean heat index categorized into four levels is provided in Figure 5. These levels are *Caution* (27 to 32 °C), *Extreme Caution* (33 to 41 °C), *Danger* (42 to 51 °C), and *Extreme Danger* (51 °C and beyond) following the heat index chart provided by the PAGASA [59]. Notably, the EBK maps are rectangularly interpolated and thus cover only the stations until the most extreme edges, i.e.,

the entirety of the terrain in Mindanao, cannot be included. The western archipelagic parts of ARMM, some areas in Surigao del Norte, and others in the western and southern parts are therefore not coverable.

The EBK rainfall Map in Figure 4 shows reduced rainfall by a quarter, especially in the BARMM, Zamboanga Peninsula, and SOCCSKSARGEN. The interpolation scale visible in the legend includes zero for JJA and SON. In succession, the DJF and MAM quarters had 41.33 and 4.01 mm of rainfall as baselines. On the other hand, Figure 5 shows that most of the areas in Mindanao were exposed to at least Extreme Caution levels of heat index throughout the year except for DJF.

3.1. Summarized Exposure of Mindanao to Environmental Stressors

The PAGASA released several advisories [59] from the onset of the forthcoming episode until its end. There was a total of seven advisories that

provided brief digests on the effects of El Niño in Mindanao from February to July of the year 2019. In general, dry spells and droughts due to mildly lesser to critically below-normal amounts of rainfall, as well as higher ranges of ambient temperatures, were experienced in Mindanao. In addition, the final Situational Report of the National Disaster Risk Reduction and Management Council (NDRRMC) released on August 23, 2019, shows that the total damages until April 2019 already reached almost eight billion (approximately 14 billion US Dollars) and around 92 million pesos (approximately 1.6 million US Dollars) cost of assistance was distributed. The Philippines sustained large-scale damages as the El Niño episode prevailed. Table 1 shows a briefer of the onslaught suffered by the agricultural industry in Mindanao alone. Herein, PAGASA [60] defines a *dry spell* as the event of a below-normal amount of rainfall by around 21% to 60% on average. In comparison, a *drought* is characterized by an over 60% rainfall reduction.

3.2. Damages to Critical Agricultural Production Sectors

Natural risks are nothing new for Philippine farmers [25]. The FAO stated that droughts, floods, cyclones, and other shocks periodically impact towns throughout the archipelago, causing considerable damage. Population expansion and climate change are two variables that increase the country's social and economic consequences of natural catastrophes. Given their existing vulnerabilities, given their vulnerabilities, it is easy to comprehend why specific communities find it progressively challenging to recover after a disaster [42].

This is especially true with small-scale farmers with numerous such families in Mindanao. They make a living by cultivating rice, corn, and various fruits and vegetables in an area commonly regarded as the breadbasket of the Philippines. When drought strikes Mindanao, individual households suffer, and food supplies and trade are disrupted for the entire nation [42].

In Situation Report No. 24 of the NDRRMC, more than 92,000 farmers and fisherfolks were affected. The same report showed that of the total damages in the country, BARMM was severely

impacted with losses of at least 374 million pesos (more than 6.5 million US Dollars) and 262 million pesos (close to 4.6 million US Dollars) to rice and corn, respectively, as seen in Appendix 1 (Supplementary Material). The extreme impacts also caused a waste of around 293 million pesos (more than 5 million US Dollars) of costs to the Zamboanga Peninsula for rice production alone and close to 328 million pesos (more than 5.7 million US Dollars) for corn production in Northern Mindanao. The drought and dry spells hit more than 247 thousand total farmers, whereas nearly 43 thousand are from Mindanao. The distribution of the affected farmers is shown in Appendix 2 (Supplementary Material). Further, in succession, around 19 thousand hectares of arable lands in BARMM and SOCCSKSARGEN were damaged, as seen in Appendix 3 (Supplementary Material).

The FAO emphasized that acting before vulnerable farming communities experience stress protects assets, ensures food security, and maximizes local agriculture as potential stabilizers [42]. Although the El Niño episode in late 2018 to mid-2019 still caused critical losses for the farmers, its influence on their whole way of life was significantly reduced, especially for those families who could develop alternate revenue sources through the project, according to the FAO [42]. The FAO relied on national and local authorities responsible for meteorological services, disaster risk reduction, and disaster management while establishing the early warning systems for drought in Mindanao. The FAO and its partners were able to monitor critical indicators that forecast shocks and initiate preventative action when they surpass predefined thresholds [42]. This strategy was essential to the efficacy of the treatments because it ensured that the short-term anticipatory activities would contribute to the more extensive process of establishing long-term resilience in farming and fishing communities in Mindanao FAO (2020). Additionally, the national government has framed a *National Drought Plan for the Philippines* [42] released in April 2019 based on the learnings gathered in 2015-2016, where 85% of provinces were impacted by the massive agricultural and fishery production losses that the drought caused.

3.3. Some Impacts on the Populations and Human

Health

Using the data publicized by the Epidemiology Bureau of the Department of Health (DOH) through the Philippine Health Statistics for 2018 [63] and

2019 [64], some diseases that were associated with increased temperature are shown in Table 1. Every Specific Death Rate (SDR) is based on the per 100,000 population of each administrative region in

Table 1. Comparison of SDR by region of some climate-sensitive diseases.

Diseases	BARMM	Caraga	DavaoReg	NorMin	SOCCS SARGEN	ZamboPen
maln18	0.6	2.9	2.1	3.9	2.7	3.5
maln19	0.2	3.2	3.0	4.7	2.0	3.0
% change	-0.4	0.3	0.9	0.8	-0.7	-0.5
heart18	20.0	88.2	110.9	122.7	84.7	121.9
heart19	17.0	97.7	119.3	130.6	88.5	133.1
% change	-3.0	9.5	8.4	7.9	3.8	11.2
cvd18	9.5	54.9	76.9	51.7	49.7	47.1
cvd19	5.1	56.8	80.3	51.6	49.3	50.7
% change	-4.4	1.9	3.4	-0.1	-0.4	3.6
pneu18	5.2	49.2	52.7	50.0	34.4	32.7
pneu19	3.9	49.5	62.0	52.1	38.1	33.2
% change	-1.3	0.3	9.3	2.1	3.7	0.5
clrd18	2.9	18.9	19.8	21.1	20.0	20.4
clrd19	2.6	20.6	24.0	21.7	24.8	21.7
% change	-0.3	1.7	4.2	0.6	4.8	1.3
liver18	0.7	13.2	10.6	11.2	7.7	8.6
liver19	0.8	13.5	10.5	11.8	8.0	9.9
% change	0.1	0.3	-0.1	0.6	0.3	1.3
diab18	3.7	29.6	31.5	29.9	27.0	25.1
diab19	3.0	35.5	33.8	30.1	28.6	27.5
% change	-0.7	5.9	2.3	0.2	1.6	2.4
dengue18	12.0	42.0	110.0	161.0	67.0	71.0
dengue19	11.0	163.0	139.0	188.0	139.0	177.0
% change	-1.0	121.0	29.0	27.0	72.0	106.0

BARMM - Bangsamoro Autonomous Region in Muslim Mindanao; Caraga - Caraga Administrative Region; DavaoReg - Davao Region; NorMin - Northern Mindanao; SOCCSKSARGEN - South Cotabato, Cotabato, Sultan Kudarat, Sarangani, and General Santos; ZamboPen - Zamboanga Peninsula; maln18 - SDR of Malnutrition in 2018; maln19 - SDR of Malnutrition in 2019; heart18 - SDR of Heart Diseases in 2018; heart19 - SDR of Heart Diseases in 2019; cvd18 - SDR of Cerebrovascular Diseases 2018; cvd19 - SDR of Cerebrovascular Diseases 2019; pneu18 - SDR of Pneumonia in 2018; pneu19 - SDR of Pneumonia in 2019; clrd18 - SDR of Chronic Lower Respiratory Diseases in 2018; clrd19 - SDR of Chronic Lower Respiratory Diseases in 2019; liver18 - SDR of Liver Diseases in 2018; liver19 - SDR of Liver Diseases in 2019; diab18 - SDR of Diabetes Mellitus in 2018; diab19 - SDR of Diabetes Mellitus in 2019; dengue18 - SDR of Dengue in 2018; dengue19 - SDR of Dengue in 2019

Mindanao. The visualizations of the comparisons between the rates per year are presented in Appendix 5 to Appendix 11 ([Supplementary Material](#)).

Table 1 shows the decreases in the percent change are quite negligible in general, although the BARMM data may be underreported due to the customs of Muslims for their dead [61]. On the other hand, it is also apparent that the different regions had increased mortalities per 100,000 in 2019. More prominently, death rates related to heart diseases in the non-BARMM regions have increased. The death rates caused by dengue have outstandingly increased as well. This could be attributed to the dengue outbreak that pushed the national government through the DOH to declare a *National Dengue Epidemic*. There is still a need for research on the connection between climate change and pneumonia, particularly in developing nations that are also severely affected by poor hygiene and lack of preparedness [62]. Nevertheless, all but BARMM regions have increased mortality rates on the said respiratory disease at varying percents, particularly in the Davao Region. The table also shows that the changes in the death rates for liver diseases, malnutrition, chronic lower respiratory diseases, and cerebrovascular diseases (stroke) are generally negligible. Primarily, the descriptive statistics in Table 1 where mortality rates (1) have increased are in parallelism with the influence of environmental stress (particularly increased temperature) as supported by most of the literature provided herein, and (2) negligible to remarkable upsurge were generally observed in the regions given the extended exposure way below average rainfall amounts as seen in Figure 4 and to higher levels of temperature as shown in Figure 5.

3.4. Future Recommendations

More collaborations from experts and other humanitarian organizations may be needed in the anticipated next ENSO event from the onset until its end. This relates to the Philippines' economic situation and natural and anthropogenically induced environmental stressors. Specific to the results, spatial and spatiotemporal models may be applied or developed for each region or lower geographical aggregates to determine how the meteorological

parameters affected the rise in deaths and potential triggering factors of dengue. This could provide evidence-based early warning systems specific to Mindanao's targeted local government units. Such action can provide a systematic approach to specified areas considering the inconclusiveness of which precise meteorological parameters promote the propagation of dengue vectors. Moreover, while the general increases in the reported SDR of the non-BARMM regions across the various selected diseases have no specifications such as the exact conditions of the patients, actual descriptions of each disease, morbidities, lifestyle, and physical environments, among others, the data suggest that a trend conspicuously exists. More scientific studies may be done to gather substantiation on how climatic stress has instigated the rise in deaths, future outcomes, and manifestations in health to the included climate-sensitive diseases discussed herein and beyond. An updated study may also be done since El Niño *is present* according to the PAGASA [59], with the trends in variable rainfall behavior and increasing temperature prevalent. More studies may also be done to understand better urban heat islands' effects on human health in specific areas in Mindanao and other locations.

4. CONCLUSIONS

The paper provides some insights into the impacts of the combination of El Niño and climate change, particularly in the prolonged period with lesser than average rainfall amounts, as well as extreme heat experienced in 2019. The science on the direct correlation between the two climate stressors is still unclear, yet the combination has devastating effects. As it is expected that (1) the climatic patterns will further worsen and (2) both ENSO events are cyclical after a few years, continuous adaptation and mitigation, as well as climate actions, should become more of a priority. Established early warning systems have been developed and could be further improved for agriculture, especially when an intense ENSO event is imminent. On the other hand, early warning systems for human health have a long way to go and need more attention, especially in highly vulnerable geographical locations. This is undoubtedly true for developing economies,

including the Philippines, which ranks as the country with the most at-risk for disasters worldwide, with Mindanao having some of the poorest populations. Further, the damage in the agricultural sector in 2019 was substantial, yet the El Niño event was still categorized as weak. The early warning systems activated by an international organization and the national government may have decreased the worst possible outcome.

AUTHOR INFORMATION

Corresponding Author

Hernan G. Pantolla — Department of Physical Sciences and Mathematics, University of the Philippines Manila, Manila-1000 (Philippines);

 orcid.org/0000-0001-7119-8083

Email: hgpantolla@up.edu.ph

Author

Alex C. Gonzaga — Department of Physical Sciences and Mathematics, University of the Philippines Manila, Manila-1000 (Philippines);

 orcid.org/0000-0002-7881-4755

Author Contributions

H. G. P. Conceptualization, obtaining the data and statistical analysis, and drafting of the manuscript; A. C. G. Supervising and reviewing.

Conflicts of Interest

The authors declare no conflict of interest.

ACKNOWLEDGEMENT

This study is a part of the dissertation of the Corresponding Author that is funded by the Philippine Statistical Research and Training Institute (PSRTI). Profound gratitude is hereby extended to the PSRTI.

SUPPORTING INFORMATION

Supplementary data associated with this article can be found in the online version at doi: [10.47352/jmans.2774-3047.212](https://doi.org/10.47352/jmans.2774-3047.212)

REFERENCES

- [1] D. S. Arndt, J. Blunden, and R. J. H. Dunn. (2020). "Introduction". *Bulletin of the American Meteorological Society*. **101** (8): S1-S8. [10.1175/2020BAMSSStateoftheClimate_Intro.1](https://doi.org/10.1175/2020BAMSSStateoftheClimate_Intro.1).
- [2] W. Cai, A. Santoso, M. Collins, B. Dewitte, C. Karamperidou, J.-S. Kug, M. Lengaigne, M. J. McPhaden, M. F. Stuecker, A. S. Taschetto, A. Timmermann, L. Wu, S.-W. Yeh, G. Wang, B. Ng, F. Jia, Y. Yang, J. Ying, X.-T. Zheng, T. Bayr, J. R. Brown, A. Capotondi, K. M. Cobb, B. Gan, T. Geng, Y.-G. Ham, F.-F. Jin, H.-S. Jo, X. Li, X. Lin, S. McGregor, J.-H. Park, K. Stein, K. Yang, L. Zhang, and W. Zhong. (2021). "Changing El Niño–Southern Oscillation in a warming climate". *Nature Reviews Earth & Environment*. **2** (9): 628-644. [10.1038/s43017-021-00199-z](https://doi.org/10.1038/s43017-021-00199-z).
- [3] M. Collins, S.-I. An, W. Cai, A. Ganachaud, E. Guilyardi, F.-F. Jin, M. Jochum, M. Lengaigne, S. Power, A. Timmermann, G. Vecchi, and A. Wittenberg. (2010). "The impact of global warming on the tropical Pacific Ocean and El Niño". *Nature Geoscience*. **3** (6): 391-397. [10.1038/ngeo868](https://doi.org/10.1038/ngeo868).
- [4] B. Edullantes, B. M. M. Concolis, R. Quilestino-Olario, D. P. D. Atup, A. Cortes, and A. T. Yñiguez. (2023). "Characteristics of Marine Heatwaves in the Philippines". *Regional Studies in Marine Science*. **62**. [10.1016/j.rsma.2023.102934](https://doi.org/10.1016/j.rsma.2023.102934).
- [5] E. R. Harrould-Kolieb. (2019). "(Re)Framing ocean acidification in the context of the United Nations Framework Convention on Climate Change (UNFCCC) and Paris Agreement". *Climate Policy*. **19** (10): 1225-1238. [10.1080/14693062.2019.1649994](https://doi.org/10.1080/14693062.2019.1649994).
- [6] R. Leichenko and J. A. Silva. (2014). "Climate change and poverty: vulnerability, impacts, and alleviation strategies". *WIREs Climate Change*. **5** (4): 539-556. [10.1002/wcc.287](https://doi.org/10.1002/wcc.287).
- [7] K. L. Akerlof, P. L. Delamater, C. R. Boules, C. R. Upperman, and C. S. Mitchell. (2015).

- "Vulnerable Populations Perceive Their Health as at Risk from Climate Change". *International Journal of Environmental Research and Public Health*. **12** (12): 15419-33. [10.3390/ijerph121214994](https://doi.org/10.3390/ijerph121214994).
- [8] E. A. Mayrhuber, M. L. A. Duckers, P. Wallner, A. Arnberger, B. Allex, L. Wiesbock, A. Wanka, F. Kolland, R. Eder, H. P. Hutter, and R. Kutalek. (2018). "Vulnerability to heatwaves and implications for public health interventions - A scoping review". *Environmental Research*. **166** : 42-54. [10.1016/j.envres.2018.05.021](https://doi.org/10.1016/j.envres.2018.05.021).
- [9] R. J. Rocque, C. Beaudoin, R. Ndjaboue, L. Cameron, L. Poirier-Bergeron, R. A. Poulin-Rheault, C. Fallon, A. C. Tricco, and H. O. Wittman. (2021). "Health effects of climate change: an overview of systematic reviews". *BMJ Open*. **11** (6): e046333. [10.1136/bmjopen-2020-046333](https://doi.org/10.1136/bmjopen-2020-046333).
- [10] M. A. Mustafa, T. Mabhaudhi, and F. Massawe. (2021). "Building a resilient and sustainable food system in a changing world – A case for climate-smart and nutrient dense crops". *Global Food Security*. **28**. [10.1016/j.gfs.2020.100477](https://doi.org/10.1016/j.gfs.2020.100477).
- [11] H. Allen, B. J. Wright, K. Harding, and L. Broffman. (2014). "The role of stigma in access to health care for the poor". *The Milbank Quarterly*. **92** (2): 289-318. [10.1111/1468-0009.12059](https://doi.org/10.1111/1468-0009.12059).
- [12] K. W. Reid, E. Vittinghoff, and M. B. Kushel. (2008). "Association between the level of housing instability, economic standing and health care access: a meta-regression". *Journal of Health Care for the Poor and Underserved*. **19** (4): 1212-28. [10.1353/hpu.0.0068](https://doi.org/10.1353/hpu.0.0068).
- [13] C. D. Santiago, M. E. Wadsworth, and J. Stump. (2011). "Socioeconomic status, neighborhood disadvantage, and poverty-related stress: Prospective effects on psychological syndromes among diverse low-income families". *Journal of Economic Psychology*. **32** (2): 218-230. [10.1016/j.joep.2009.10.008](https://doi.org/10.1016/j.joep.2009.10.008).
- [14] G. L. Beckles and C. F. Chou. (2016). "Disparities in the Prevalence of Diagnosed Diabetes - United States, 1999-2002 and 2011-2014". *Morbidity and Mortality Weekly Report*. **65** (45): 1265-1269. [10.15585/mmwr.mm6545a4](https://doi.org/10.15585/mmwr.mm6545a4).
- [15] W. M. Schultz, H. M. Kelli, J. C. Lisko, T. Varghese, J. Shen, P. Sandesara, A. A. Quyyumi, H. A. Taylor, M. Gulati, J. G. Harold, J. H. Mieres, K. C. Ferdinand, G. A. Mensah, and L. S. Sperling. (2018). "Socioeconomic Status and Cardiovascular Outcomes: Challenges and Interventions". *Circulation*. **137** (20): 2166-2178. [10.1161/CIRCULATIONAHA.117.029652](https://doi.org/10.1161/CIRCULATIONAHA.117.029652).
- [16] D. Lewer, W. Jayatunga, R. W. Aldridge, C. Edge, M. Marmot, A. Story, and A. Hayward. (2020). "Premature mortality attributable to socioeconomic inequality in England between 2003 and 2018: an observational study". *Lancet Public Health*. **5** (1): e33-e41. [10.1016/S2468-2667\(19\)30219-1](https://doi.org/10.1016/S2468-2667(19)30219-1).
- [17] J. G. Fritze, G. A. Blashki, S. Burke, and J. Wiseman. (2008). "Hope, despair and transformation: Climate change and the promotion of mental health and wellbeing". *International Journal of Mental Health Systems*. **2** (1): 13. [10.1186/1752-4458-2-13](https://doi.org/10.1186/1752-4458-2-13).
- [18] J. A. Marengo, R. Jones, L. M. Alves, and M. C. Valverde. (2009). "Future change of temperature and precipitation extremes in South America as derived from the PRECIS regional climate modeling system". *International Journal of Climatology*. **29** (15): 2241-2255. [10.1002/joc.1863](https://doi.org/10.1002/joc.1863).
- [19] K. R. Smith. (2008). "Comparative environmental health assessments". *Annals of the New York Academy of Sciences*. **1140** : 31-9. [10.1196/annals.1454.032](https://doi.org/10.1196/annals.1454.032).
- [20] S. S. Zhou, F. Huang, J. J. Wang, S. S. Zhang, Y. P. Su, and L. H. Tang. (2010). "Geographical, meteorological and vectorial factors related to malaria re-emergence in Huang-Huai River of central China". *Malaria Journal*. **9** : 337. [10.1186/1475-2875-9-337](https://doi.org/10.1186/1475-2875-9-337).
- [21] S. Lozano-Fuentes, M. H. Hayden, C. Welsh-Rodriguez, C. Ochoa-Martinez, B. Tapia-Santos, K. C. Kobylinski, C. K. Uejio, E. Zielinski-Gutierrez, L. D. Monache, A. J. Monaghan, D. F. Steinhoff, and L. Eisen. (2012). "The dengue virus mosquito vector

- Aedes aegypti* at high elevation in Mexico". *American Journal of Tropical Medicine and Hygiene*. **87** (5): 902-9. [10.4269/ajtmh.2012.12-0244](https://doi.org/10.4269/ajtmh.2012.12-0244).
- [22] B. Stone, J. J. Hess, and H. Frumkin. (2010). "Urban form and extreme heat events: are sprawling cities more vulnerable to climate change than compact cities?". *Environmental Health Perspectives*. **118** (10): 1425-8. [10.1289/ehp.0901879](https://doi.org/10.1289/ehp.0901879).
- [23] C. K. Uejio, O. V. Wilhelmi, J. S. Golden, D. M. Mills, S. P. Gulino, and J. P. Samenow. (2011). "Intra-urban societal vulnerability to extreme heat: the role of heat exposure and the built environment, socioeconomics, and neighborhood stability". *Health Place*. **17** (2): 498-507. [10.1016/j.healthplace.2010.12.005](https://doi.org/10.1016/j.healthplace.2010.12.005).
- [24] J. Samson, D. Berteaux, B. J. McGill, and M. M. Humphries. (2011). "Geographic disparities and moral hazards in the predicted impacts of climate change on human populations". *Global Ecology and Biogeography*. **20** (4): 532-544. [10.1111/j.1466-8238.2010.00632.x](https://doi.org/10.1111/j.1466-8238.2010.00632.x).
- [25] T. Kjellstrom, B. Lemke, and M. Otto. (2013). "Mapping occupational heat exposure and effects in South-East Asia: ongoing time trends 1980-2011 and future estimates to 2050". *Industrial Health*. **51** (1): 56-67. [10.2486/indhealth.2012-0174](https://doi.org/10.2486/indhealth.2012-0174).
- [26] L. Acosta-Michlik, U. Kelkar, and U. Sharma. (2008). "A critical overview: Local evidence on vulnerabilities and adaptations to global environmental change in developing countries". *Global Environmental Change*. **18** (4): 539-542. [10.1016/j.gloenvcha.2008.10.001](https://doi.org/10.1016/j.gloenvcha.2008.10.001).
- [27] M. Levi, T. Kjellstrom, and A. Baldasseroni. (2018). "Impact of climate change on occupational health and productivity: a systematic literature review focusing on workplace heat". *Medicina del Lavoro*. **109** (3): 163-79. [10.23749/mdl.v109i3.6851](https://doi.org/10.23749/mdl.v109i3.6851).
- [28] G. Lubber and M. McGeehin. (2008). "Climate change and extreme heat events". *American Journal of Preventive Medicine*. **35** (5): 429-35. [10.1016/j.amepre.2008.08.021](https://doi.org/10.1016/j.amepre.2008.08.021).
- [29] R. C. Luginbuhl, L. L. Jackson, D. N. Castillo, and K. A. Loring. (2008). "Heat-Related Deaths Among Crop Workers—United States, 1992-2006". *Morbidity and Mortality Weekly Report*. **57** (24): 649-653. [10.1001/jama.300.9.1017](https://doi.org/10.1001/jama.300.9.1017).
- [30] S. Sahu, M. Sett, and T. Kjellstrom. (2013). "Heat exposure, cardiovascular stress and work productivity in rice harvesters in India: implications for a climate change future". *Industrial Health*. **51** (4): 424-31. [10.2486/indhealth.2013-0006](https://doi.org/10.2486/indhealth.2013-0006).
- [31] T. Kjellstrom and J. Crowe. (2011). "Climate Change, Workplace Heat Exposure, and Occupational Health and Productivity in Central America". *International Journal of Occupational and Environmental Health*. **17** (3): 270-281. [10.1179/oeh.2011.17.3.270](https://doi.org/10.1179/oeh.2011.17.3.270).
- [32] M. L. Parry. (2007). "Climate change 2007-impacts, adaptation and vulnerability: Working group II contribution to the fourth assessment report of the IPCC". Cambridge University Press.
- [33] G. P. Yumul Junior, N. A. Cruz, N. T. Servando, and C. B. Dimalanta. (2008). "The meteorologically abnormal year of 2006 and natural disasters in the Philippines". *Episodes*. **31** (4): 378-383. [10.18814/epiiugs/2008/v31i4/002](https://doi.org/10.18814/epiiugs/2008/v31i4/002).
- [34] R. Briones, E. Antonio, C. Habito, E. Porio, and D. Songco. (2017). "Strategic review: Food security and nutrition in the Philippines". *World Food Program*.
- [35] C. Reyes, J. Bancolita, N. L. Leyso, and S. J. Calubayan. (2014). "Impacts of climate change on household food security in the Philippines". *Food and Agricultural Organization-Community Based Management System*.
- [36] G. Ziervogel and P. J. Ericksen. (2010). "Adapting to climate change to sustain food security". *WIREs Climate Change*. **1** (4): 525-540. [10.1002/wcc.56](https://doi.org/10.1002/wcc.56).
- [37] M. Laskari, G. Menexes, I. Kalfas, I. Gatzolis, and C. Dordas. (2022). "Water Stress Effects on the Morphological, Physiological Characteristics of Maize (*Zea mays* L.), and on Environmental Cost".

- Agronomy*. **12** (10). [10.3390/agronomy12102386](https://doi.org/10.3390/agronomy12102386).
- [38] D. R. K. Saikant, S. Kumar, M. Rani, A. Sharma, S. Srivastava, D. Vyas, G. A. Singh, and S. Kumar. (2023). "A Comprehensive Review on Climate Change Adaptation Strategies and Challenges in Agriculture". *International Journal of Environment and Climate Change*. **13** (11): 10-19. [10.9734/ijecc/2023/v13i113138](https://doi.org/10.9734/ijecc/2023/v13i113138).
- [39] A. Saad-Hussein, H. K. Ramadan, A. Bareedy, and R. Elwakil. (2022). "Role of Climate Change in Changing Hepatic Health Maps". *Current Environmental Health Reports*. **9** (2): 299-314. [10.1007/s40572-022-00352-w](https://doi.org/10.1007/s40572-022-00352-w).
- [40] T. Hák, S. Janoušková, and B. Moldan. (2016). "Sustainable Development Goals: A need for relevant indicators". *Ecological Indicators*. **60** : 565-573. [10.1016/j.ecolind.2015.08.003](https://doi.org/10.1016/j.ecolind.2015.08.003).
- [41] E. F. Huesca. (2016). In: " Human Insecurities in Southeast Asia, (Asia in Transition, ch. Chapter 11". 173-192. [10.1007/978-981-10-2245-6_11](https://doi.org/10.1007/978-981-10-2245-6_11).
- [42] W. Gao, Z. Wang, and H. Huang. (2022). "Variations of the Eco-Hydro-Climatic Environment Response to the 2015/2016 Super El Niño Event in the Mindanao Dome Upwelling System". *Journal of Ocean University of China*. **21** (1): 69-80. [10.1007/s11802-022-4695-x](https://doi.org/10.1007/s11802-022-4695-x).
- [43] E. M. Vo, F. P. Lansigan, A. M. Salazar, C. L. Khan, D. V. Faustino-Eslava, R. A. Luyun, and N. C. Altoveros. (2017). "Smarter approaches to reinvigorate agriculture as an industry in the Philippines (project SARAI)".
- [44] G. B. Anderson, M. L. Bell, and R. D. Peng. (2013). "Methods to calculate the heat index as an exposure metric in environmental health research". *Environmental Health Perspectives*. **121** (10): 1111-9. [10.1289/ehp.1206273](https://doi.org/10.1289/ehp.1206273).
- [45] P. K. Suprpto, I. R. Husna, V. Meylani, and A. Wibowo. (2023). "Spatial Estimations of Suitable Intertidal Habitats for Conservations of Sea Urchin Community in Sancang Coast, West Java". *Journal of Multidisciplinary Applied Natural Science*. **3** (2): 113-121. [10.47352/jmans.2774-3047.162](https://doi.org/10.47352/jmans.2774-3047.162).
- [46] E. B. Anderes. (2012). In: "Encyclopedia of Environmetrics". [10.1002/9780470057339.vak003.pub2](https://doi.org/10.1002/9780470057339.vak003.pub2).
- [47] J. Wang, Q. Meng, C. Yang, P. Ren, and M. Santamouris. (2023). "Spray optimization to enhance the cooling performance of transparent roofs in hot-humid areas". *Energy and Buildings*. **286**. [10.1016/j.enbuild.2023.112929](https://doi.org/10.1016/j.enbuild.2023.112929).
- [48] H. Staiger, G. Laschewski, and A. Gratz. (2012). "The perceived temperature - a versatile index for the assessment of the human thermal environment. Part A: scientific basics". *International Journal of Biometeorology*. **56** (1): 165-76. [10.1007/s00484-011-0409-6](https://doi.org/10.1007/s00484-011-0409-6).
- [49] M. Cheng, Y. Wang, B. Engel, W. Zhang, H. Peng, X. Chen, and H. Xia. (2017). "Performance Assessment of Spatial Interpolation of Precipitation for Hydrological Process Simulation in the Three Gorges Basin". *Water*. **9** (11). [10.3390/w9110838](https://doi.org/10.3390/w9110838).
- [50] C. Fan, S. Yin, and D. Chen. (2021). "Spatial correlations of daily precipitation over mainland China". *International Journal of Climatology*. **41** (14): 6350-6365. [10.1002/joc.7199](https://doi.org/10.1002/joc.7199).
- [51] R. Yang and B. Xing. (2021). "A Comparison of the Performance of Different Interpolation Methods in Replicating Rainfall Magnitudes under Different Climatic Conditions in Chongqing Province (China)". *Atmosphere*. **12** (10). [10.3390/atmos12101318](https://doi.org/10.3390/atmos12101318).
- [52] G. Ali, M. Sajjad, S. Kanwal, T. Xiao, S. Khalid, F. Shoaib, and H. N. Gul. (2021). "Spatial-temporal characterization of rainfall in Pakistan during the past half-century (1961 -2020)". *Scientific Reports*. **11** (1): 6935. [10.1038/s41598-021-86412-x](https://doi.org/10.1038/s41598-021-86412-x).
- [53] B. Sahu, A. K. Ghosh, and Seema. (2021). "Deterministic and geostatistical models for predicting soil organic carbon in a 60 ha farm on Inceptisol in Varanasi, India". *Geoderma Regional*. **26**. [10.1016/j.geodrs.2021.e00413](https://doi.org/10.1016/j.geodrs.2021.e00413).

- [54] K. Krivoruchko and A. Gribov. (2014). In: "Mathematics of Planet Earth, (Lecture Notes in Earth System Sciences, ch. Chapter 15". 61-64. [10.1007/978-3-642-32408-6_15](https://doi.org/10.1007/978-3-642-32408-6_15).
- [55] R. Rajesh, L. Elango, and K. Brindha. (2019). In: "GIS and Geostatistical Techniques for Groundwater Science". 57-78. [10.1016/b978-0-12-815413-7.00006-7](https://doi.org/10.1016/b978-0-12-815413-7.00006-7).
- [56] J. K. Ord and A. Getis. (2010). "Local Spatial Autocorrelation Statistics: Distributional Issues and an Application". *Geographical Analysis*. **27** (4): 286-306. [10.1111/j.1538-4632.1995.tb00912.x](https://doi.org/10.1111/j.1538-4632.1995.tb00912.x).
- [57] M. Ghodousi, A. Sadeghi-Niaraki, F. Rabiee, and S.-M. Choi. (2020). "Spatial-Temporal Analysis of Point Distribution Pattern of Schools Using Spatial Autocorrelation Indices in Bojnourd City". *Sustainability*. **12** (18). [10.3390/su12187755](https://doi.org/10.3390/su12187755).
- [58] J. Mesquitela, L. B. Elvas, J. C. Ferreira, and L. Nunes. (2022). "Data Analytics Process over Road Accidents Data—A Case Study of Lisbon City". *ISPRS International Journal of Geo-Information*. **11** (2). [10.3390/ijgi11020143](https://doi.org/10.3390/ijgi11020143).
- [59] F. Hilario, R. d. Guzman, D. Ortega, P. Hayman, and B. Alexander. (2009). "El Niño Southern Oscillation in the Philippines: Impacts, Forecasts, and Risk Management". *Philippine Journal of Development*. **66**.
- [60] A. M. O. Mohamed, E. K. Paleologos, and F. Howari.(2020)." Pollution assessment for sustainable practices in applied sciences and engineering". Butterworth-Heinemann.
- [61] A. R. Gatrad. (1994). "Muslim customs surrounding death, bereavement, postmortem examinations, and organ transplants". *BMJ*. **309** (6953): 521-3. [10.1136/bmj.309.6953.521](https://doi.org/10.1136/bmj.309.6953.521).
- [62] J.-M. N. Kayembe and H.-C. N. Kayembe. (2017). In: "Contemporary Topics of Pneumonia, ch. Chapter 2". [10.5772/intechopen.71609](https://doi.org/10.5772/intechopen.71609).