I INTRODUCTION

1.1 Background

Globally, smallholder farmers contribute to world food production and food supply (Ricciardi *et al.* 2018). Indonesia is one of the agricultural countries in Southeast Asia, where most of the population consumes rice as primary food. Hence, Indonesia becomes the biggest rice consumer in Asia (Yuliawan and Handoko 2016). FAO (2017) stated that the agriculture ministry's strategic plan 2015-2019 aims to achieve food sovereignty and enhance farmers' welfare in Indonesia since it contributes to Indonesia's GDP with 10.26 % growth in 2010-2014 (Rafani 2015). Smallholder farmers comprise a group that could balance the food security of Indonesia through their small farming activities. On the other hand, agriculture is one of the most vulnerable sectors to climate change risks.

Explicitly, Agriculture, forests, economy, human health, and well-being can be influenced negatively through the temperature rise and rainfall variation as the main component of the climate system (Fussel 2007; Karmeshu 2015). Recently WMO (2020) confirmed the year 2019 as the second hottest year after 2016. Future climate projections specify that wet and mid-latitude regions will experience a frequent intensification of rainfall whereas, the sub-tropical, dry region will see the opposite result (IPCC 2014). Ministry of Foreign Affairs of the Netherlands (2018) reported that Indonesia had experienced climate change with frequent droughts, heatwaves, floods, cyclone intensity across the country, and sea-level rise effects on coastal areas that could be counted as a threat to the country's development.

Furthermore, during 1994-2014 significant part of tropical forests has been transformed into dry cultivation, shrubs, and urban areas in West Java, Indonesia (Siswanto and Francés 2019). Expansion of cultivated land and urban areas has occurred due to higher demand for food and settlement (Siswanto and Francés 2019). Land cover change is the main contributor to climate change. IPCC (2000) reported that from 1850 to 1998, approximately 136 Gt Carbon emissions were caused by land-use changes.

In particular, climate change dramatically influences crop productivity, food supply, and food security (US-GCRP 2014). Explicitly, temperature and rainfall fluctuation can disturb agricultural production (Syaukat 2011). IPCC (2014) reported that tropical region's food security challenges would be intensified by climate change. The agriculture sector is suffering most from the adverse impact of climate change. Specifically, rice paddy production has been reduced since 2000, influencing the country's food security. (Syuaib 2016; Takama 2014). A significant part of Indonesian farmers relies on rain-fed agriculture systems, particularly on rain-fed rice production. It is considered a low-yield farming system due to its high reliance on the rainy season calendar (Hayashi *et al.* 2018). Yuliawan and Handoko (2016) revealed that irrigated rice production has more yield than rain-fed rice production. Moreover, there is decreased trend in both irrigated and rain-fed rice production with increased temperature in every province of Indonesia. Water availability plays a significant role in boosting food security. Water-related disasters, namely drought, and flood, are severe issues in Indonesia that cause water insecurity (Mursidi 2017; Pratiwi *et al.* 2020).

Smallholder farmers in Indonesia are practicing traditional farming systems without access to the latest agricultural tools, technology, and improved seed varieties. Further, a significant part of Indonesian farmers are smallholders, yet 10% practice a high mechanization level (FAO 2018). However, technology contributes to agriculture development, but crop production can be regulated by climate and weather conditions. (Syaukat 2011). Both adaptation and mitigation measures are required to deal with climate change. Farmer's responses could play a significant role in fighting with changing climate and rising agricultural production.

This study investigates trends in temperature and rainfall, land cover changes, and smallholder farmers' perception and responses against climate change in Dramaga Sub-district. Dramaga, Bogor is a part of west java, Indonesia, which most of its population are busy with agricultural activities. Household farming, small farming system, and women participation in Dramaga village play a leading role in the daily income. Thus, smallholder farmers in the study area are the leading group advancing the country's food security. The focuse of the study is on the decision-maker and related stakeholders who need to understand the recent changes in weather and climate patterns, land-use changes, and farmers' responses against climate change. They can contribute to creating appropriate environmentally friendly sustainable technology and innovation for self-sufficient agriculture and food security.

1.2 Problem Statement

According to Ruri, Owner of the organic farm. (Pers. Comm, 14-Jan-2020), smallholder farmers in sub-district Dramaga are the particularly vulnerable group to climate change as smallholder farmers rely on their surrounded resources, land, and rain-fed agriculture. Their cultural and socio-physical behaviors are matter to achieve resilience and sustainable crop production. On the other hand, adaptation and mitigation to climate change have been limited due to the: (1) lack of detailed information and capacity to adapt and mitigate the climate change. (2) political weakness in decision-making processes and gaps in communication between stakeholders on the local scale. Adaptation to climate change depends on vast sources of information and the latest technology (Klein 2011). The capacity of farmers to adapt and mitigate climate change can be significantly influenced by farmers' climate change knowledge, access to the latest environmental information sources, and environmentally sustainable practices.

1.3 Research Questions

To address the research problem, the following research questions were investigated and hypotheses tested:

1. To what extent weather patterns and land cover are changed in the past few decades?
2. What are climate change impacts identified by smallholder farmers?
3. How the smallholder farmers make the respond to the changing climate?

1.4 Objectives

The main objectives of this research are as below:

1. To examine climate variability, land cover changes, climate change impacts experienced by smallholder farmers, and adaptation and mitigation measures have been implemented through their cultural, and socio-physical behaviors.
2. To provide recommendations for relevant stakeholders to increase farmer's resilience against climate change, and innovation of environmentally sustainable technology and practices.

1.5 Scope of the Study

The study focuses on smallholder vulnerability to climate change impacts and their physical and cultural behavior to examine how they overcome it. This is a comprehensive study covering climate variability and pattern analysis of the last three decades in the Dramaga sub-district, land cover changes assessment in the last two decades, and smallholder responses to climate change.

The thesis is structured in 5 chapters where; the first chapter outlines the background of the study, problem statement, objective, research framework, and significance of the study. Chapter 2 detailed the literature review, where the chapter 3 explains materials and methods. Chapter 4 decribes results and discussions of the study, where the last Chapter, 5 reports conclusion and recommendations.

1.6 Conceptual Framework

Figure 1 represents food security's vulnerability through changing climate. Farmers in Indonesia are the most vulnerable group affected by the adverse impact of climate change. In particular, changes in temperature and rainfall would reduce the volume of annual agricultural production. On the other side, advancing food security depends on farmer's adaptive capacity and behaviors to deal with climate change. Thus, decision-makers need to contribute to environmentally sustainable technology for self-sufficient agriculture and advancing food security.

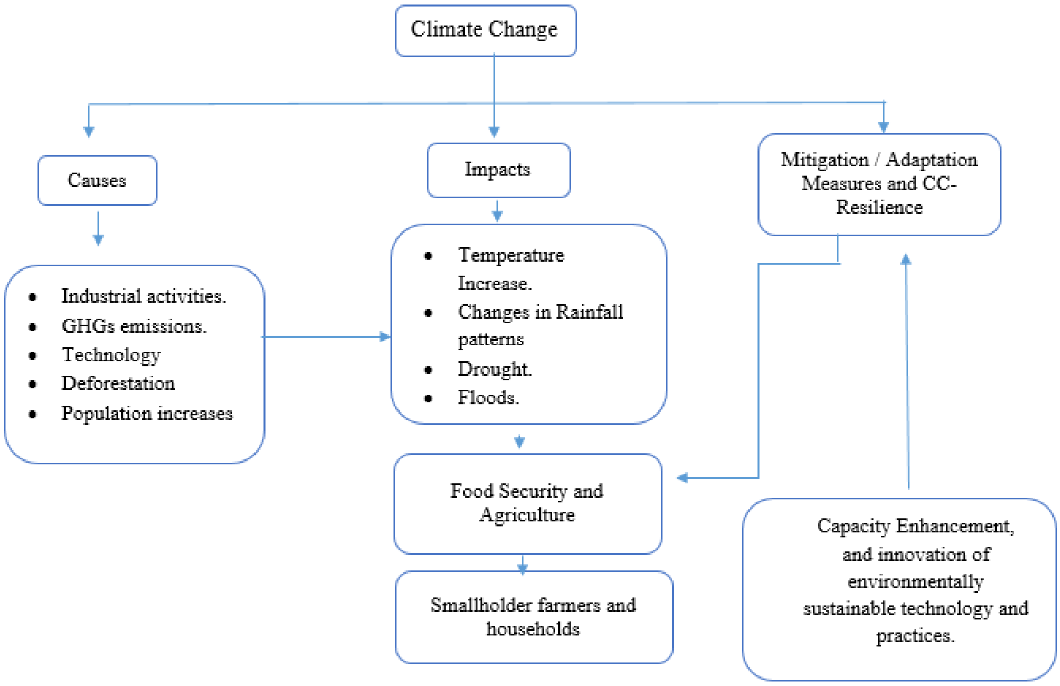

Figure 1.1. Research framework

1.7 Significane of the Study

This study's findings will help the policymakers, decision-maker, and all key stakeholders identify weather patterns, land cover changes, climate change impacts felt by smallholder farmers, and their answers against climate change. Thus, the study will let the decision-makers prioritize their project based on the community's vulnerabilities. As to maintain food security and climate change resilience through innovation of environmentally sustainable technology, mitigation, and adaptation practices. Resultantly, this study will redound to the benefit of households and smallholder farmers to have a sustainable, self-sufficient small farming agriculture system with the fitting annual income.

II LITERATURE REVIEW

2.1 Agriculture and Climate Change

Indonesia's agriculture sector performs a vital position in advancing food security and is also known as its economy's backbone. Agriculture ties to employment, income, and livelihood of Indonesian communities. The bulk of Indonesians depend on agricultural production. Rice is considered the main crop in Indonesia. In particular, Java island is a great giver of rice production in Indonesia (Panuju *et al.* 2013). Besides, agriculture adds to Indonesia's GDP with 10.26 % growth in 2010-2014. It occupied around 35.76 million laborers, approximately 30.20 % of the national labor force in 2014 (Rafani 2015). However, a significant part of Indonesian farmers is smallholders. Yet, 10% of them practice a high level of mechanization (FAO 2018), but Smallholder farmers are the primary driver of advancing food security. ADB (2015) reported that a 7% annual increase in smallholder productivity could increase $50 billion in agricultural revenues until 2030. On the other hand, climate change magnifies agricultural vulnerabilities since temperature rise and precipitation trends lead to reduced crop production (Syaukat 2011b).

Indonesia is suffering from actual climate variabilities with its complex topographical characteristic. Due to the changing climate, natural disasters, including extreme weather events such as floods and long dry seasons, threaten Indonesia and millions of people in the region. However, precipitation magnitude plays a prominent role in water availability, agriculture development, food security, and the country's economy (State Ministry of Environment 2007; Patle dan Libang 2014; World Bank 2014; Hidayat 2016). IPCC (2014) reported that tropical region's food security challenges would be intensified by climate change. While extreme temperature and precipitation can reduce crop growth US-EPA (2017), the temperature rises negatively depending on optimal crop temperature for reproduction (US-GCRP 2014). Further, climate projections specify that wet and mid-latitude regions will experience a frequent intensification of rainfall whereas, the sub-tropical, dry region will see the opposite result (IPCC 2014). According to the National Action Plan of Indonesia (2007), every hundred years, Jakarta's temperature is increasing by 1.42Co in July and 1.04 C^o in January. Besides, the climate differs, seasonal variation, and typically temperature rise leads to water reserves reduction. In Particular, the islands of Java and Bali will receive the risk of floods and drought, decreasing trend in the dry season and increasing rainfall rate in the rainy season. Ramdhan *et al.*, (2018) study simulation predicts that Bogor city would face water scarcity by 2031.

Most smallholder farmers in Indonesia rely on rain-fed agriculture. Ullah, Mulatsih, and Anwar (2014) stated that 42.70% of smallholder farmers in the Bogor regency have access to water pump facilities for irrigating their farms. In contrast, the rest are depending on rain-fed agriculture. Farming activities are the backbone of smallholder farmers' socio-economic benefits, as they depend on agriculture products. Ullah, Mulatsih, and Anwar (2014) reported that Mustard green, cucumber, eggplant, long beans, sweet potatoes, spinach, onions, and tomatoes are considered the main vegetables and food crops in Bogor. In 2014, 71.87% of smallholder farmers were satisfied with their products and farming activities. Meanwhile, many factors, including financial resources, climate events such as heavy rainfall, the high price of high-quality seeds, and high technology price, assume 28.13% of farmer's un-satisfaction in Bogor regency. Most smallholder farmers are willing to sell their agriculture products to the traditional selling markets, and hence, most of them provide their products only to the local markets Farmers. Perception level about agriculture development identified low, as 13.54 % of farmers as farmers group members had essential awareness about agriculture development and assume that 97.92% of them need further training (Ullah, Mulatsih, and Anwar 2014).

2.2 Land Cover Changes

Song *et al.*, (2018) concluded that 60% of changes in the world's land cover were caused by direct human land-use activities, while 40% of the trends linked with indirect human impacts such as climate change in 1982-2016. Also, agriculture expansion is the primary driver of land transformation as well. Explicitly, in the past centuries, agriculture was the main factor of land cover conversion (Foley *et al.* 2006).

Land in Indonesia is changing mainly due to deforestation and rapid urbanization. These changes contribute to global warming. Indonesia is considered the third-largest tropical forest cover after Brazil and the Democratic Republic of Congo. (Rustiadi *et al.* 2002; Margono *et al.* 2014). Forest land cover transformation is the primary, recognized type of land cover change. Deforestation in Indonesia started particularly on Java island before 1880 (Foley *et al.* 2006). Saputra and Lee, (2019) land cover projection revealed increases of 4% in plantation area and 1.2% and 1.6% declines in forest and crop areas in Indonesia till 2050 and 2070. While changes in tropical forest cover significantly lead to GHGs emissions (Margono *et al.* 2014). According to Rustiadi *et al.*, (2002), 51.51% of Jakarta city's total land converted from agriculture to urban, and 15,002.12 ha (4,21%) land in Bogor changed from agriculture into urban areas during 1972-2001. Additionally, forests were also replaced by agricultural land in Indonesia; for instance, 3,584.13 ha of Bogor land changed from the forest into agriculture from 1972-2001 (Rustiadi *et al.* 2002). During 1994-2014 significant part of tropical forest has been transformed into dry cultivation, shrubs, and urban areas in West Java, Indonesia (Siswanto and Francés 2019). Expansion of cultivated land and urban areas occurred due to higher demand for food and settlement (Siswanto and Francés 2019).

2.3 Adaptation Practices

Studies have shown a decrease in annual rainfall, maximum and minimum temperature increases in West Java. Meanwhile, the decrease of rice yield reduction was considered effectual output from farmers' adaptation practices such as plantation time and irrigation scheduling (Candradijaya *et al.* 2014). Farm plots limitation among smallholder farmers in West Java identified as rice insufficiency factor in the household level where adapted households with their adaptive capacity assume a great rice sufficiency level (Candradijaya 2015).

Providing climate adaptive capacity and practices such as crop variation, changing planting time, and new crop introduction can be successful short-term tools for increasing farming system resilience (Shikuku *et al.* 2017). New crop variation provides drought resistance, heat toleration, salinity toleration, and crop fast-maturing smallholder farmers' opportunities (Vermeulen *et al.* 2011; Lybbert and Sumner 2012). According to Tessema, Joerin and Patt, 2018; based on farmers' experience sharing, changing planting time and crop type as a non-technological adaptation to climate change on farm level can decline climate change risk. Land management in agriculture is also known as the initial step to combat climate change risks. Rice, corn, soybean, green bean, groundnut, and so on crops as part of rain-fed agriculture products in Indonesia requires appropriate land management system, as rain-fed agriculture called a way to achieve self-sufficient food availability in Indonesia (Sulaiman *et al.* 2019). Water management is a critical adaptation tool to climate change and technological efficiencies such as laser leveling, sprinklers, and drip irrigation. In contrast, water resources are not considered an effective solution for agriculture (Cohn *et al.* 2017). A slight reduction in food production among smallholder farmers can let them hunger, poverty, trap them there, civil conflict, and migration to other urban and rural regions (Cohn *et al.* 2017). Meanwhile, job opportunities loss, less chance to achieve self-sufficient agriculture, and food security might be affected by climate change impacts.

2.4 Mitigation Practices

Smallholder farmers count as fundamental donors to climate change through land-use changes and land preparation, including forest land transformation and slash and burn systems (Rudel *et al.*, 2009; Tinker, Ingram, and Struwe, 1996). Slash and burn are a generic term of the agriculture system where farmers slash the vegetation, keep it dry, and burn it before cultivation. This system is used for land preparation as the soil could achieve more nutrients from biomass burning, including all plans and livestock remains. Plus, the slash and burn system aims to prevent pests and other diseases in agriculture (Hauser and Norgrove 2013). In Indonesia, slash and burn are traditional methods where farmers have been applying for a long time. This method is known among farmers due to less cost and high efficiency in the farming system (Ketterings *et al.* 1999). Bio-char is one of the most effective and efficient solutions for farmers instead of slash and burn systems. This system is cheaper and easier to be applied using plants and livestock biomass. The bio-char method in agriculture is considered as mitigation to climate change (Mekuria and Noble 2013).

Producing beef, soybeans, palm oil, and wood products in commodity agriculture plays a significant role in 40% forest loss worldwide (Seekell and Odorico 2018). Conservation tillage, mulching, improved manure, pasture utilization, and composting measure among land-use strategies and soil and livestock management are considered significant opportunities for smallholder farmers to be implemented (Defries and Rosenzweig 2010). Agroforestry is a valuable climate change mitigation measure considered in the agriculture sector. Agroforestry measures provide less non-CO2 gas emission (Rosenstock *et al.* 2014). Agroforestry is along with socio-economic benefits for farmers and rural development. Farmers need to understand the existence value of agroforestry as mitigation to climate change. farmers with agroforestry practice get more income and high labor productivity rather than the traditional farming system (De Giusti *et al.* 2019).

According to IPCC, 2000; Agroforestry provides the highest Carbon sequestration potential and one of the most excellent mitigation options against changing climate through GHGs accumulation from the atmosphere. On the other hand, agroforestry provides diversity in production methods, especially among smallholder farmers. This option can be counted as an adaptation to climate change. Meanwhile, smallholder farmers' adaptive capacity in developing countries is limited due to their dependence on the natural system and lack of institutional support. Agroforestry also creates opportunities for the vulnerable group to adapt to climate change's negative outcome (Verchot *et al.* 2007). According to Kaczan, Arslan and Lipper, 2013; agroforestry is considered a climate-smart agriculture system. Agroforestry, including planting trees and shrubs species and food crops, increase; soil cover maintenance, nutrient level enhancement, an increase of soil organic matter, increase of water filtration, and increased source for a secondary source of food as fodder, fiber ad fuel. Agroforestry leads to support the food security and socio-economic benefits of farmers (Kaczan *et al.* 2013).

2.5 Organic Farming

Organic farming is one of the sustainable farming systems using eco-friendly technology. Organic fertilizer and overall land, water, and crop management, which aims to achieve sustainable agriculture in harmony with nature, is called organic farming. Organic farming might increase plant growth, rice seedling numbers, plant strengthen enhancement against pests and diseases, soil fertility level enhancement, and rice taste increases (Rochayati 2011). (Teasdale, J.R., Banowetz, G., Griffith, S., Mueller-Warrant, G. Whittaker, J., Kennedy 2007) concluded that Organic agriculture CO2 sequestration level is much higher rather than conventional agriculture system.

Indonesia’s government concerns the improvement of organic farming among farmers as they invested 5200 Million Indonesian Rupiah on organic farming system certification development in 2009. The farmers use manure from plant residues as a nutrient for cultivation; furthermore, they make green compost using plant residues or legumes from the cultivation field. To access the eco-friendly agriculture farming system, they consider making bio-pesticide as well (Rochayati 2011). According to Rochayati, 2011; farmers are using *Alpinia galanga*, *Andropogon nardus*, mix and boil for almost twelve hours with 10 L water can produce one litter bio-pesticide, and can be used watery along with 10 L water.

According to FAO 2019; agriculture is one of the main contributors to climate change, GHGs emission from different agriculture activities, including; enteric fermentation, rice cultivation, synthetic fertilizer, manure applied to soils, manure left on pasture, manure management, crop residues, cultivation of organic soils, burning of crop residues, burning of savanna and energy use. Smallholder farmer’s adaptive capacity, environmentally friendly technology, and mitigation innovation are the initial tools to achieve self-sufficient agriculture and food security. Hence, further research in enhancing farmer’s capacity and advancing food security needs to be conducted.

III MATERIALS AND METHODS

3.1. Study Area

Dramaga Sub-District lies between 06^{o} 31' 30" to 06^{o} 37' 30" south latitude and 106^{o} 45' 30" to 106^{o} 42' 30" east longitude with an approximately 207-meter elevation above sea level. Dramaga occupies a 24,37 KM^2 area consist of ten villages (BPS-Statistics of Bogor 2020) (Figure 3.1). The climate is tropical with rainy and dry seasons. The wet season starts from November to April, and the dry season comprises May to October. The mean annual temperature is estimated 26.3 C^{o} in 2019 (BMKG 2020b). The majority of households rely on agricultural activities as their primary source of daily income and support food security. Rainfall rate plays a significant role in rain-fed agriculture and the source of drinking water as well.

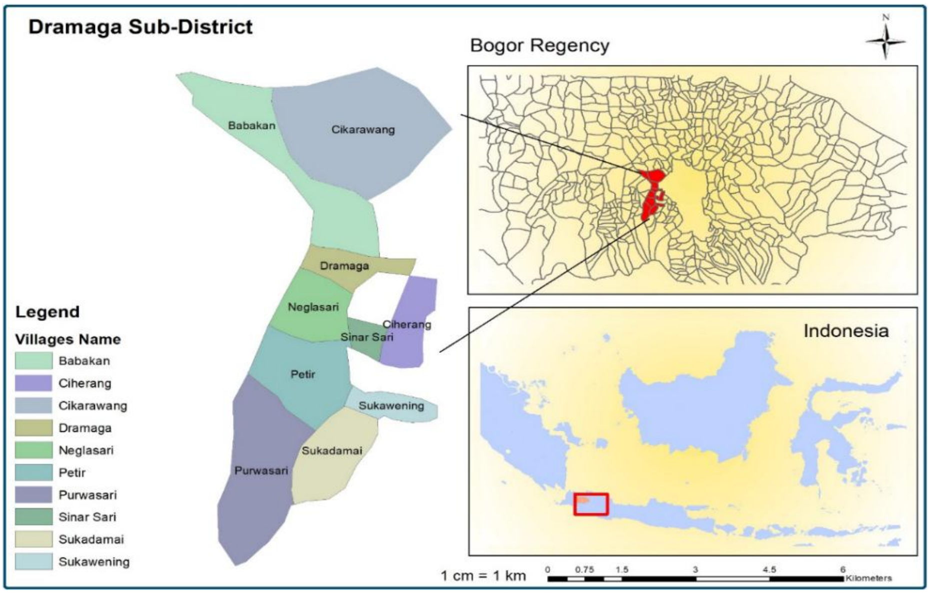

Figure 3.1. *Study location Map*

3.2. Data Sources

Monthly rainfall and temperature data were collected from Dramaga Climatology Station of Bogor Meteorology, Climatology, and Geophysics Agency BMKG in the period of 1990-2019.

To examin land cover changes, satellite imageries Landsat 7 for the year 2000 and land sat eight operation land manager (OLI) for 2020 with the 30 m x 30 m resolution have been obtained from USGS online system.

Furthermore, for assessing farmers responses to climate change, 85 household farmers among 600 smallholder farmers from the two villages (Purwasari and Cikarawang) have been selected for interviews through random sampling. The data have been obtained from the field survey using a structured questionnaire and interview with closed and open-ended questions. The Likert scale has been applied in the questionnaire to indicate the level of agreement and disagreement.

Table 3.1. Dramaga sub-District annual rainfall and temperature in 2019

District	Mean Temp	Max Temp	Min Temp	Mean Rainfall
Dramaga	26.3 C°	33.7 C°	21 C°	3659 mm

3..3 Methods

The descriptive statistics such as mean, standards deviation SD and coefficient of variation CV of temperature and rainfall data were computed. This shows the variation and fluctuation of the data. A higher CV value determines great variability, and a lower CV value shows less variability in the data (Asfaw *et al.* 2018). The CV is computed using the following statistical formula:

$$CV = \frac{\sigma}{\mu} \times 100 \quad (3.1)$$

Where:
CV = Coefficient of Variation, σ = Standards Deviation, and μ = mean.

A simple linear regression model with the coefficient of determination R^2 has been run to analyze the trends in the time series of temperature and rainfall data. The regression model statistical formula is given as below:

$$y = aX + b \quad (3.2)$$

Where:
X = time, a= slope coefficient and b = lease square estimate of the intercept.

The slope coefficient determines changes in the unit of time. The positive slope coefficient value indicates an increase trend and the negative sign shows the decreasing trend in the model (Motiee and McBean 2009). The linear regression model has been run in Microsoft Excel 2019.

The Mann-Kendall test has been computed to test the trends statistically. The Mann-Kendall's test, known as MK statistical non-parametric test, usually has been used for environmental, hydrological, and meteorological time series trend analysis. To run the test, it does not require the data to be normally distributed. According to the MK test null hypothesis indicates that there is no trend in the series and the alternative hypothesis determines that there is a trend in the series (SHENG YUE and CHUNYUANWANG 2004; Panda and Sahu 2019) To interpret the MK test result P-value can be compared with the alpha=0.05. The smaller p-value rather than alpha 0.05, rejects the null hypothesis H_0, whereas a greater p-value rather than alpha 0.05 cannot reject the null hypothesis H_0. The MK test statistical formula can be defined as below:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \operatorname{sgn}(xj - xk)$$

(3.3)

Where:
Sgn (xj−xk) =+1 (if xj−xk >0), 0 (if xj−xk =0) or -1 (if xj−xk <0).

MK test uses for time series of n data point and Xj and Xk taken as two subsets of the data (Motiee dan McBean 2009) This test is run to a time series of Xk, ranked from k=1,2…, n-1, that is ranked from j=i+1, i+2…, n. Each data point of Xj derived as a reference point. A higher positive value of S is equal to an increasing trend but a lower negative value identifies a declining trend (Panda dan Sahu 2019). Further, Kendall's Tau value highlights the correlation among variables (Karmeshu 2015). The MK test has been computed through XLSTAT 2020 software.

To analyze land cover changes, Geometric correction (*Geo-referencing)* using ArcGis has been run to bring images into actual geographical position. Further, The UTM geographic coordination system has been used for image processing. Moreover, the unifying process has been applied to combine seven bands of images (*Composite*). To detect the land cover changes between 2000 and 2020, *supervised classification* through the maximum likelihood method has been carried out. The classification consisted of 6 classes: Forest, Agriculture, Vegetation, Bare Land, Built-up, and water bodies. To enhance the classification accuracy, *a ground truthing* method has been run using Google earth pro. Further, the land cover maps for the years 2000 and 2020 have been prepared using Arc GIS. The raster data has been converted into a vector to calculate the area. Moreover, through the spatial analysis toolbox, *the dissolve* and *intersect* method have been run to estimate the changes and create the land-use changes map for the Bogor regency and Dramaga sub-district between 2000 and 2020. The GIS 10.2 software has been used for spatial analysis of the images.

To find out farmer's perception level and their responsive measures, descriptive statistics such as mean and standards deviation have been computed. A Chi-square test has been run to determine the association among variables. Chi-square test ($\chi 2$ test) has been run to find out associations among variables such as Climate change perception and gender, Climate change perception and Education level, and climate change perception and mitigation practices. The Chi-square test is a statistical test that measures the association between two categorical variables (Ugoni and Walker 1995). Moreover, SPSS v26 and Microsoft Excel 2016 were used for data analysis and visualization.

$$x^2 = \sum \frac{(0-E)^2}{E} \tag{3.4}$$

Where:

x^2 = Chi Square obtained

Σ = The sum of

O = Observed Score

E = Expected Score

IV RESULTS AND DISCUSSIONS

4.1. Variability and Time Series Trend Analysis of Rainfall and Temperature

4.1.1 Precipitation

According to the obtained data, the Dramaga sub-district has experienced an annual mean rainfall of 387,8 mm in the past 30 years. Where descriptive statistics Table 4.1 reveals the monthly average rainfall of 1990-2019 with a huge variation. The month of July indicates the lowest, and November the highest mean rainfall of 193 mm and 439 mm, respectively. The rainy season starts from November until April, where the dry season comprises six months from May until October each year. May and August's months have the lowest and highest extent of rainfall fluctuation with 31.72 and 73.92 coefficient of variation, respectively. Figure 4.1 describes the rainfall pattern for the last three decades. Rainfall decline can be seen in March, April, and May in the last decade (2010-2019), Where the first decade (1990-1999) determines a high precipitation rate in March and April. Meanwhile, the rainfall rate in November has the highest rate in the last decade. The computed time series trend analysis of rainfall through linear regression in figure 4.2 shows a decrease trend during the wet season with the negative regression slop value 11.117. Simultaneously dry season time series regression model in figure 4.3 explains a decreasing rainfall of 4.931,3 mm by increasing each period. The dry season decrease trend is less significant compared with the wet season. Overall annual mean rainfall with the regression slope of -13.441 in figure 4.4 indicates a decreasing trend through an increase of each period of 1990-2019. Annual precipitation rates play a significant role in the agriculture sector mainly, where farmers rely on rain-fed agriculture. Monthly average rainfall data shows significant variation in the past three decades. Whereas unpredictable rainfall and variation may cause several natural hazards such as floods and landslides. Recently, continuously and heavy rainfall affected 409,000 people through flooding in Jakarta, Bogor, and surrounded regions in January 2020 (ActAlliance 2020).

The MK test has been computed compared to the linear regression model to the obtained rainfall data in 1990-2019. Table 4.2 explains the MK statistical test summary with the 5% significance level. The conducted MK test indicates no trends in the annual, wet, and dry season rainfall series. As the computed P-value for the annual, wet, and dry season rainfall are 0.143, 0.239, and 0.372, respectively, which represent the greater P-Value rather than significance level alpha = 0.05; hence, it fails to reject the null hypothesis. However, the linear regression equation has a decreasing trend in the annual and seasonal rainfall. Statistically, the MK test result reveals no significant trend in the annual and seasonal rainfall in the Dramaga area in 1990-2019. Hence, this finding is not similar to Indonesia's national historical climate data that shows an increasing trend of 12% precipitation in the country level from 1985-2015 (United States Agency for International Development - USAID 2018). Local topography, altitude, and slope are significantly correlated with the annual mean rainfall (Al-Ahmadi and Al-Ahmadi 2014). Geographical characteristics such as elevation, topographical variation, and mountains in Bogor consist of the lowest 107 m until the highest 789 m above the sea level (BPS-Statistics of Bogor 2020) can be considered as the main factor affecting rainfall variation in Bogor Regency.

Table 4.1. Descriptive statistical summary of monthly mean rainfall (1990-2019).

Variable	Observations (Year)	Minimum (mm)	Maximum (mm)	Mean (mm)	Std. deviation	Coefficient of Variation CV(%)
Jan	30	133	704	386	146.4	37.91
Feb	30	86	612	384	123.9	32.24
Mar	30	99	744	351	168.3	47.96
Apr	30	43	669	398	156.7	39.41
May	30	118	571	352	111.7	31.72
Jun	30	51	686	246	139.3	56.63
Jul	30	2	404	193	123.1	63.73
Aug	30	10	647	210	154.9	73.92
Sep	30	22	603	251	144.9	57.64
Oct	30	111	584	351	129.4	36.84
Nov	30	179	855	439	161.3	36.74
Dec	30	72	583	317	131.1	41.43

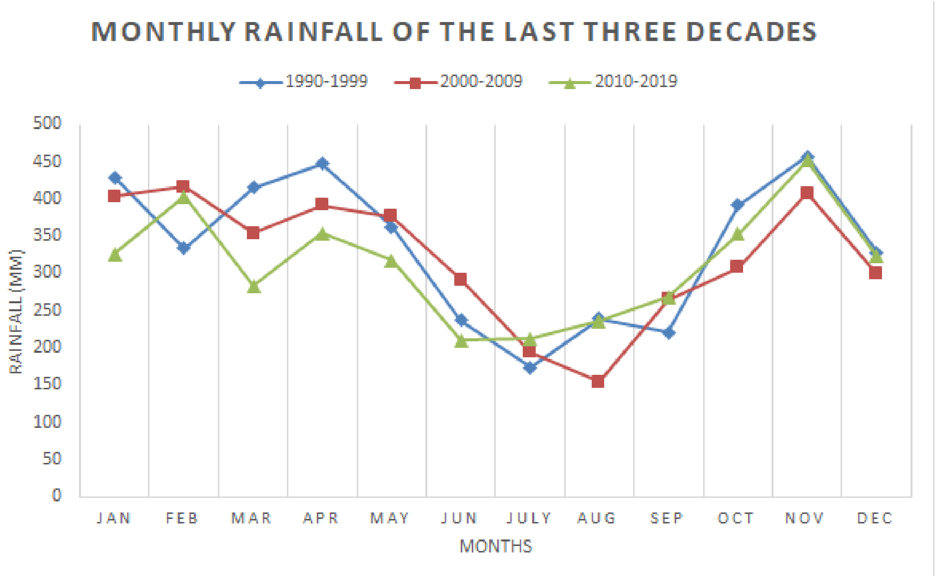

Figure 4.1. Monthly mean rainfall pattern of 1990-2019 period.

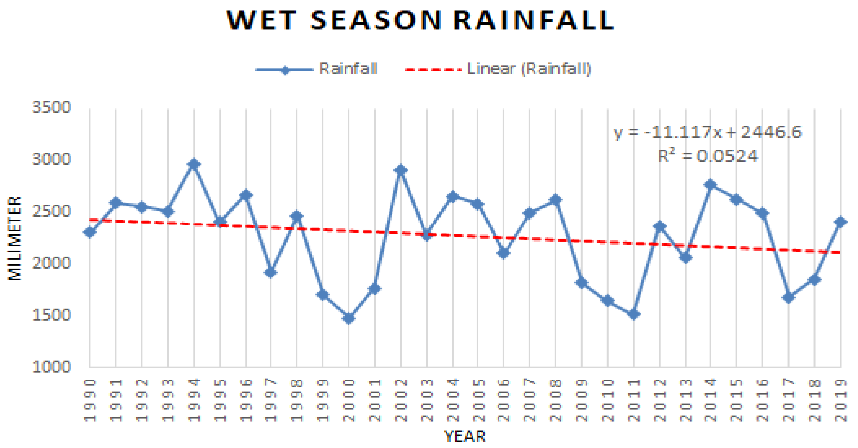

Figure 4.2. Linear regression slope of wet season (Nov-Apr) mean rainfall of 1990-2019 period.

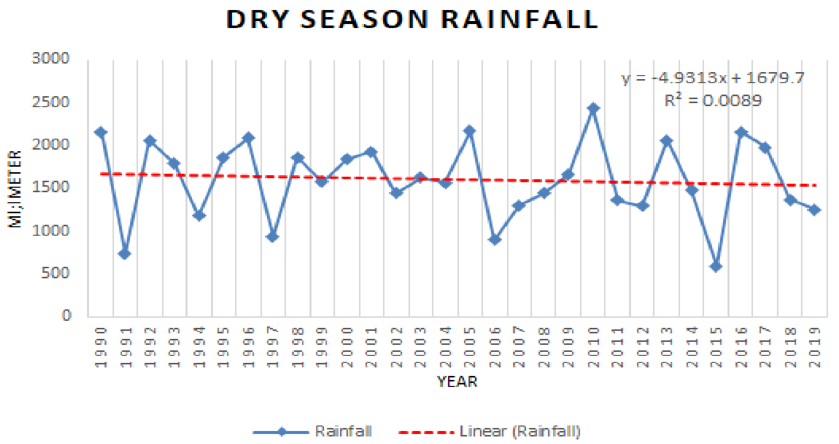

Figure 4.3. Linear regression slope of dry season (May-Oct) mean rainfall of 1990-2019 period.

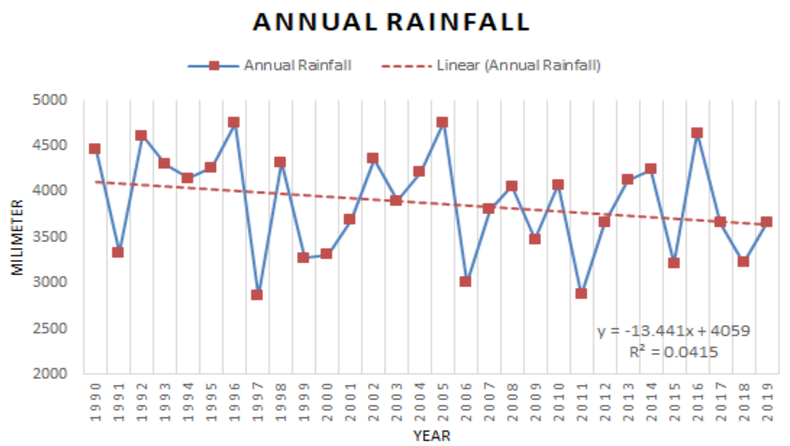

Figure 4.4. Linear Regression of annual mean rainfall of 1990-2019 period.

Table 4.2. Mann-Kendall's statistical test summary for the seasonal and annual mean rainfall (1990-2019).

Variable	Kendall's tau	MK Test Statistic (S)	Var (S)	p-value (Two-tailed)	Alpha	Std. deviation	Mean
Annual Rainfall	-0.191	-83.000	3141.667	0.143	0.05	563.3	3877.5
Wet Season Rainfall	-0.154	-67.000	3141.667	0.239	0.05	427.554	2274.2
Dry Season Rainfall	-0.117	-51.000	3141.667	0.372	0.05	458.892	1603.2

4.1.2 Temperature

Temperature variability in Table 4.3 shows the high fluctuation in January and less in August with the 1.9452 and 1.2049 coefficient of variation, respectively. Based on average temperature February and May are the coldest and warmest months in the period of 1990-2019 with the 25.2° and 26.2° mean, respectively. The last ten years (2010-2019) counted as the warmest decade in the past 30 years (Figure 4.5). These ten years experienced warmer weather conditions in April and May months with the 27.1 centigrade mean temperature in the last 30 years. Meanwhile, the second decade (2000-2009) average temperature from January until June was colder compared to the first and third decade. The month February average temperature in 2000-2009 with 25.5 centigrade can be considered the coldest month among others in the past three decades. The computed simple linear regression trend model for annual mean temperature data display an increasing trend with the regression slope value of 0.0251 and 0.3555 R2 value (Figure 4.6). At the same time, the annual maximum (Figure 4.7) and minimum temperature (Figure 4.8) show an increasing trend with the 0.0378, 0.0226 regression slope value and 0.2401 and 0.0873 R2 value, respectively.

To find out statistical significance and comparison with the linear regression model, the MK statistical test has been run for the obtained data of annual mean, maximum, and minimum temperature data in the period of 1990-2019. Table 4.4 explains Mann-Kendall's test summary that indicates increasing trends in the annual mean and annual maximum temperature. The P-value for the annual mean and maximum temperature are 0.001 and 0.006, which are smaller than alpha 0.05. Therefore, it rejects the null hypothesis H_0. Meantime, the P-value of annual minimum temperature is 0.378 and greater than alpha =0.05 that, fails to reject the null hypotheses H_0 and hence, no trend detected in the annual minimum temperature series.

Climate variability, particularly temperature rise concern, is a global phenomenon, while warming is happening in the earth's atmosphere. Linear regression slope determines significant correlations with the MK statistical test result for the annual mean and maximum temperature except for the annual minimum temperature. These findings are similar to the IPCC report (2014), where they listed 1983-2012 the warmest years in the earth's histor.

Table 4.3. Descriptive statistical summary of monthly mean temperature (1990-2019).

Variable	Observations	Minimum (Centigrade)	Maximum (Centigrade)	Mean (Centigrade)	Std. deviation	CV %
Jan	30	24.5	26.4	25.3	0.493	1.9452
Feb	30	24.4	25.9	25.2	0.405	1.6082
Mar	30	24.9	26.4	25.6	0.346	1.3471
Apr	30	25.4	27.1	26.0	0.441	1.6923
May	30	25.3	27.1	26.2	0.397	1.5141
Jun	30	25.3	26.5	25.8	0.322	1.2474
Jul	30	24.9	26.1	25.5	0.338	1.3218
Aug	30	25.2	26.3	25.6	0.309	1.2049
Sep	30	25.3	26.6	25.9	0.330	1.2739
Oct	30	25.1	26.8	26.0	0.442	1.6962
Nov	30	24.9	26.9	25.9	0.411	1.5841
Dec	30	24.8	26.3	25.7	0.396	1.5423

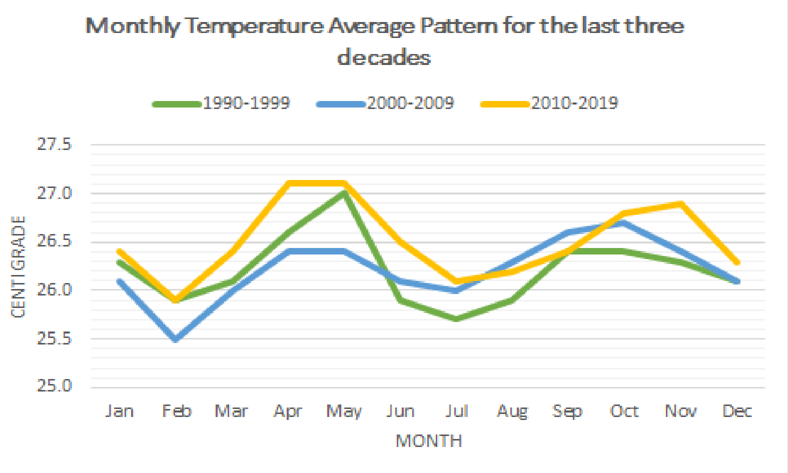

Figure 4.5. Monthly mean temperature pattern of the last three decades.

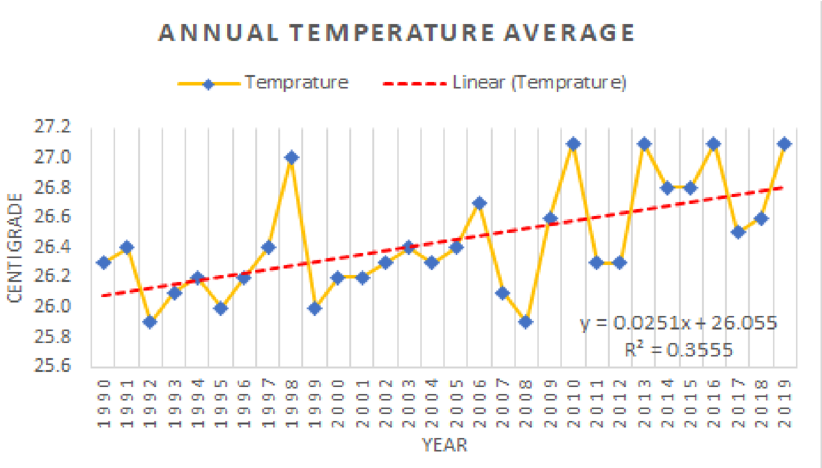

Figure 4.6. linear regression slope of the annual mean temperature (1990-2019).

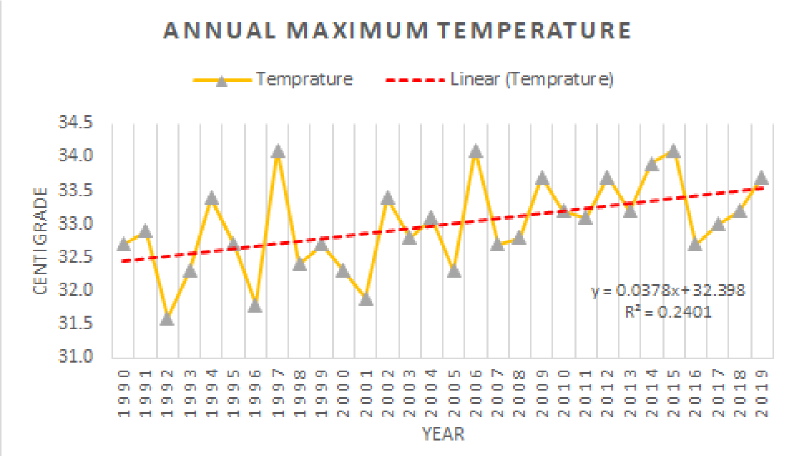

Figure 4.7. Linear regression slope of annual maximum temperature (1990-2019).

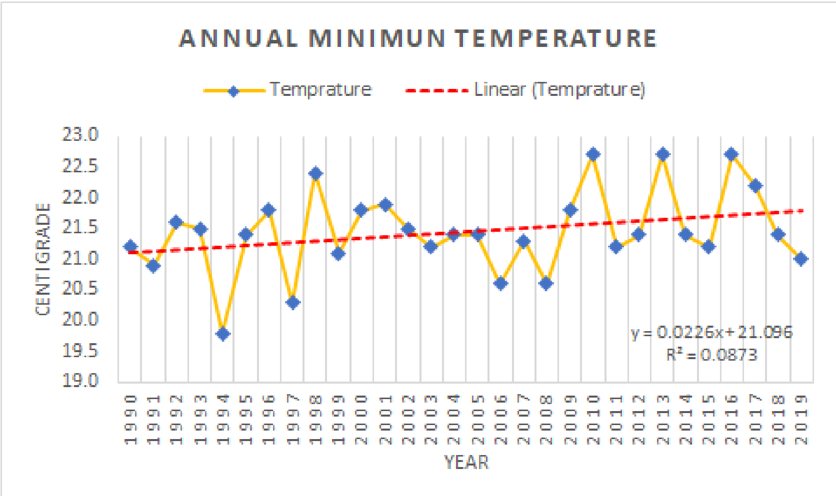

Figure 4.8. Linear Regression slope of annual minimum temperature (1990-2019).

Table 4.4. Mann-Kendall's statistical test summary for the annual mean, max, and min temperature (1990-2019).

Variable	Kendall's tau	MK Test Statistic (S)	Var(S)	p-value (Two-tailed)	alpha	Std. deviation	Mean
Annual Mean Temperature	0.454	190.000	3094.000	0.001	0.05	0.370	26.4
Annual Maximum Temperature	0.365	154.000	3107.333	0.006	0.05	0.678	32.9
Annual Minimum Temperature	0.119	50.000	3095.333	0.378	0.05	0.674	21.4

4.2. Land Cover Changes Assessment between 2000 and 2020

4.2.1. Land Cover Changes in Bogor Regency

The GIS analysis revealed that land cover in Bogor had been changed since 2000. Table 4.5 displays that the built-up area has been expanded audaciously in Bogor. Moreover, agriculture development played a significant role in land cover changes as well. A great part of Bogor's regency expanded into agricultural/cultivated land. Figure 4.9 shows that bare land enlargement has also been occurring in the Bogor regency. The conversion of forest, agriculture, and vegetation to bare land can be considered the primary land cover trends. Considerable areas in Bogor converted from vegetation – Agriculture (27.2%), Vegetation – Built-up (12.1%), Vegetation – Bare land (9.6%), forest-agriculture (9.7%), and Forest – built up (4.8%). These changes have been occurred due to human activities and their daily demand for development. On the other hand, the bare land transformation has happened as well. Where 8.4% of bare land has been changed into agriculture. 121,604 ha area has been changed in Bogor regency since 2000 -2020. Where Bogor regency covers almost 266,385 ha area (BPS-Statistics of Bogor 2020). Rustiadi *et al.*, (2002), concluded that approximately 15,002.12 ha of agricultural land had been converted into the built-up area in Bogor from 1972-2001. He also expressed that most agricultural land in Jakarta, Bekasi, Tangerang, and Depok also changed into urban due to rapid population growth and economic development. Bogor regency comprises mountain forest, vegetation extent, and diverse topography play an important role in regulating local climate and ecosystem services. On the other side, Bogor lies close to Jakarta city, the main concentrated region for the economy and urban development for the past few decades. Overall, built-up areas such as commercial places, residential, development, and transportation might be the main factors of rapid land cover conversion in Bogor and surrounded regions..

Land-use change is the main contributor to climate change. Chen *et al.*, (2006) found that built-up areas such as roads have the highest temperature. According to IPCC (2000), from 1850 to 1998, around 136 Gt Carbon emissions were caused by land-use changes. Where carbon emissions are the primary driver of global climate change, deforestation may provide more reflection of solar radiation. As vegetation and forest could keep stable, the process of evapotranspiration among plants and atmosphere (Britannica 2021). Thus, land cover changes and deforestation can be the driver of global warming on the earth. Bogor is prone to natural disasters such as floods, as Bogor is known as the city of rain. Hence, land cover changes might raise flood frequency and intensity. The surface of built-up areas cannot store rainwater anymore (Merten *et al.* 2020). According to Moe *et al.*, (2017), projection of flood in Jakarta, land-use changes, and land subsidence have been increased flood inundation volume around 36.8% from 2013 to 2050.

Table 4.5. Land Cover Changes in Bogor Regency between 2000 and 2020.

Land Cover Changes	Area Changes (Ha)	Changes (%)
Water Body - Built Up	24.30	+0.02%
Water Body - Agriculture	12.62	+0.01%
Water Body - Bare Land	29.79	+0.02%
Vegetation - Built Up	14,808.66	+12.18%
Vegetation - Agriculture	33,159.83	+27.27%
Vegetation - Bare Land	11,699.04	+9.62%
Forest - Built Up	5,912.0	+4.86%
Forest - Agriculture	11,852.17	+9.75%
Forest - Vegetation	4,071.66	+3.35%
Forest - Bare Land	1,714.93	+1.41%
Agriculture - Water Body	13.01	+0.01%
Agriculture - Built Up	2,485.50	+2.04%
Agriculture - Bare Land	2,047.29	+1.68%
Bare Land - Water Body	94.90	+0.08%
Bare Land - Built Up	4,104.55	+3.38%
Bare Land - Agriculture	10,239.14	+8.42%
Bare Land - Vegetation	19,335.11	+15.90%
	121,604.51	

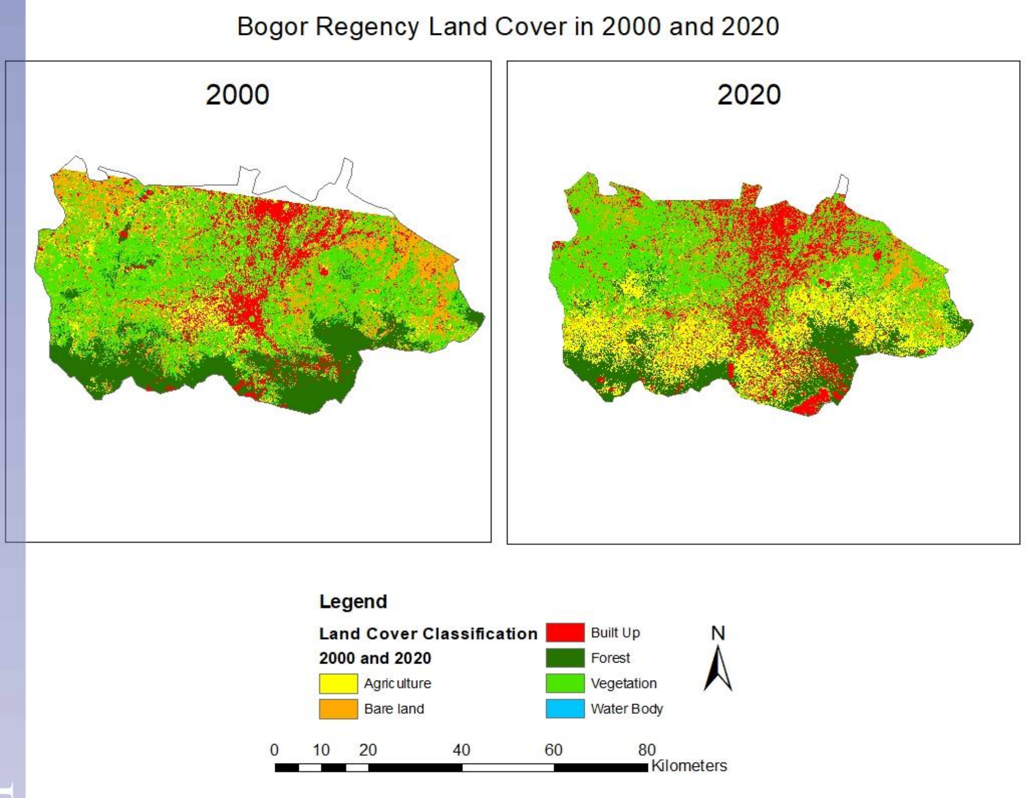

Figure 4.9. Bogor Regency Land Cover maps in 2000 and 2020.

4.2.2. Land Cover Changes in Dramaga Sub-district

Findings indicated that approximately 6.88 Km2 land cover had been changed in Dramaga Sub-district in the past 20 years (Table 4.6). Where Dramaga Sub-district covers 2,437 ha area in total (BPS-Statistics of Bogor 2020). A significant part of the area in Dramaga has been converted into agriculture/cultivated land. Nearly 24% of vegetation land has been changed into agriculture. Moreover, 10.8% of vegetation converted into built-up areas as well. Forest conversion in Dramaga cannot be considered a significant trend for changing the local climate condition due to Dramaga’s small area coverage. However, our GIS analysis discovered forest conversion to agriculture, vegetation, built-up, and bare land. Forest transformation into agriculture caused due to increasing demand for food. Most of the households in Dramaga rely on small farming. Figure 4.10 displays rapid agriculture expansion and land cover differences from 2000 – 2020. This finding supported by (Siswanto dan Francés 2019) which stated that the conversion of the forest into cultivation areas in the upper Citarum watershed, Indonesia (dry cultivations, plantations, and rice fields) was caused by the rise of food requirements due to the population growth as reflected in the increase of urban areas. IPB university in Dramaga sub-district has increased the demand for student settlements, housing, and other facilities, including restaurants, coffee shops, study areas, and transportation facilities. Traffic jams in the Dramaga area, including Bogor city, are caused by significant parts of IPB staff, teachers, and students' activities.

Table 4.6. Dramaga Sub-district land cover changes between 2000 and 2020.

Land Cover Changes	Area Change (Ha)	Changes (%)
Vegetation - Built Up	74.3	+10.8%
Vegetation - Agriculture	169.7	+24.7%
Vegetation - Bare Land	80.0	+11.6%
Forest - Built Up	2.3	+0.3%
Forest - Agriculture	3.5	+0.5%
Forest - Vegetation	7.1	+1.0%
Forest - Bare Land	1.6	+0.2%
Agriculture - Built Up	4.7	+15.2%
Agriculture - Bare Land	79.6	+11.6%
Bare Land - Built Up	22.2	+3.2%
Bare Land - Agriculture	56.8	+8.3%
Bare Land - Vegetation	86.6	+12.6%
	688.4	

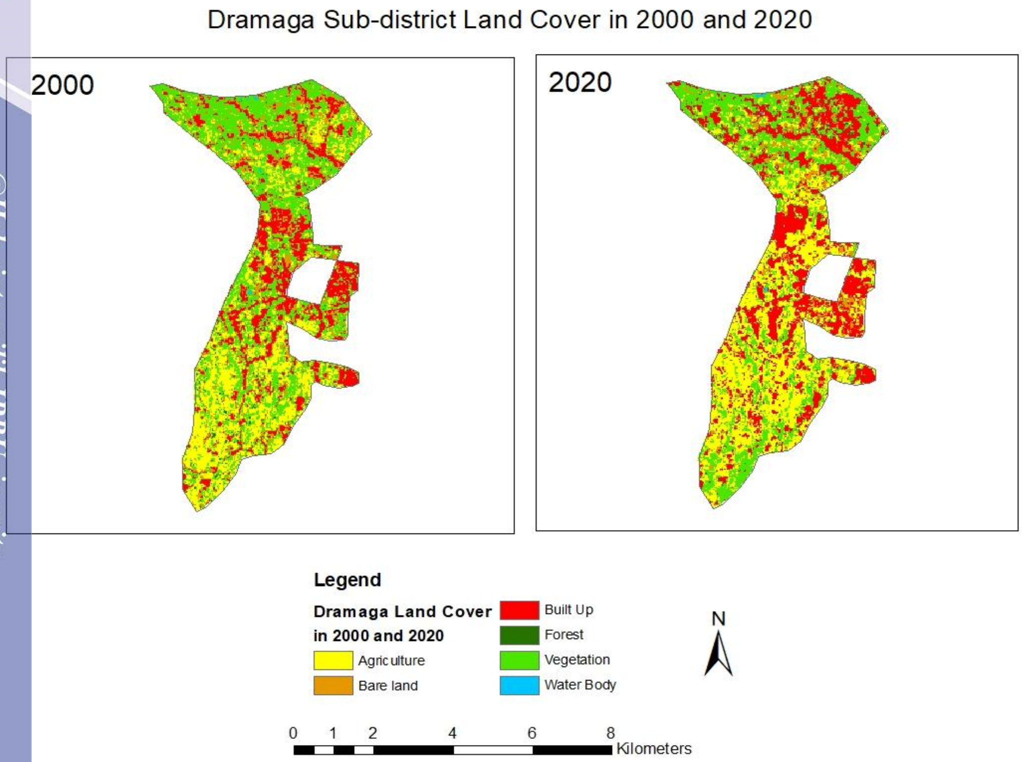

Figure 4.10. Dramaga Sub-district land cover maps in 2000 and 2020.

4.3. Smallholder Farmers Responses to Climate Change

4.3.1. Socio-demographic Profile of the Respondents

Table 4.7 presents that majority of the respondents were male. Moreover, more than half of respondents among the 85 farmers were elder ages (over 50 years old). Most of the farmer's education level has been estimated less than elementary school. Table 4.8 illustrates that a more significant part of farmers has an annual income between 16-29 million IDR (1,150-2,070 USD) from each ha land. Meanwhile, Indonesia, with its tropical climate, includes three cultivation and harvest seasons. There is one month break after each harvest. Eggplant, Garlic, Sweet Potato, Cassava, Maize, Rice (Paddy), Banana, Spinach, and Cucumber are the farmers' initial agricultural products in Bogor, Indonesia.

Table 4.7. The Socio-demographic Profile of the Respondents shows Gender, Age, and education level with its frequency and percentage.

Variables	Frequency	Percentage
Gender		
Male	55	65%
Female	30	35%
Age		
14-25	0	0%
26-38	5	6%
39-49	30	35%
50-Over	50	59%
Education		
Less than elementary level (*Illiterate*)	15	18%
Elementary to less than High School	40	47%
High School	30	35%
University or Above	0	0%

Table 4.8. The annual income level of smallholder farmers has been categorized based on the obtained data from the survey. According to the farmer's respondents, we created three groups of income level as below. Most smallholder farmers have the medium income level.

Income Level	Annual Income/Ha	Frequency	Percentage %
Low	3-15 Million IDR (1 USD=14000 IDR)	35	41%
Medium	16-29 Million IDR	40	47%
High	30 Million IDR -Over	10	12%

4.3.2. Perception of Climate Change

Climate change perception among smallholder farmers is various Table 4.9 Farmers are experiencing the impact of climate change, mainly temperature rise and precipitation changes (Figure 4.11). Our result explains that most of the farmers have been heard the word about climate change. On the other hand, the findings indicate that mitigation and adaptation words have not been most familiar among the farmers, with the mean of 2.92 and 3.33, respectively. Indonesia suffers from natural disasters and unusual weather events, but Indonesian farmers' average answer is estimated with a mean of 3.73. Meanwhile, Jakarta, Bogor, and the surrounding region have experienced massive floods due to heavy rainfall in January 2020 (ActAlliance 2020). Farmers believe that the dry season is getting longer in comparison to the past. Further, farmers' experiences tell that the amount of agricultural crop has declined due to climate change. This finding is supported by Kusumasari (2016), which stated that java island experiences a shorter rainy season that starts late and stops earlier with the same amount of rainfall and the higher intensity. Meantime, she expressed that, climate change decreases agricultural products by quantity and quality as well. Findings reveal that most smallholder farmers received climate-related training and capacity-building programs for governmental agencies with the 4.60 means. Chi-square test result shows a significant association between climate change perception and gender ($\chi2$=17.183, df=3, and P=.001). Meanwhile, a positive association was detected between education level and climate change perception ($\chi2$=23.886, df=6, and P=.001). Our result is supported by Falaki *et al* (2013) where they reported a positive association between gender and climate perception among farmers. It's also concluded by Acquah and Onumah (2011) that education can enhance the level of climate change perception.

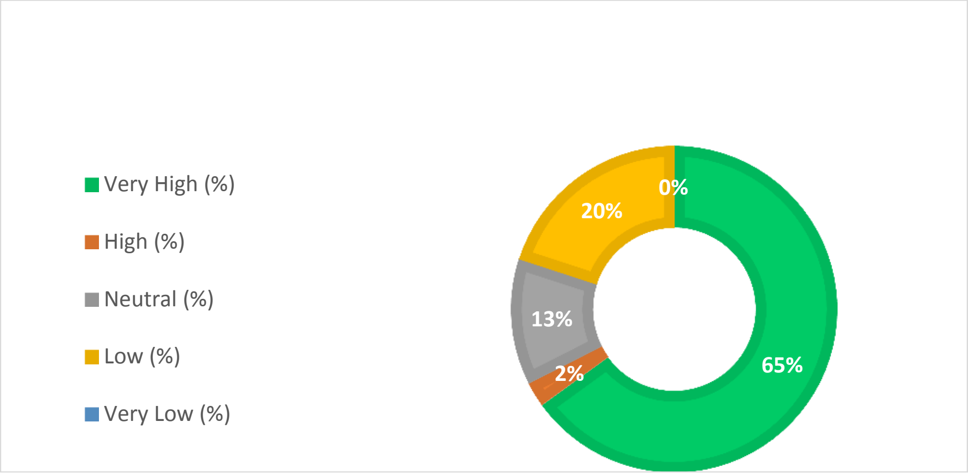

Figure 4.11. Farmers have been felt changing climate condition.

Table 4.9. farmer's perception level towards climate change based on the below attitudinal statements.

Statements	Mean	SD
I believe that weather conditions have changed (precipitation and temperature) compared to the past.	4.13	1.265
I have heard the word Climate Change.	4.75	.494
I have heard the word Climate Change mitigation.	2.92	1.979
I have heard the word Climate Change Adaptation.	3.33	1.421
Climate change means to me Temperature rise.	4.88	.404
Climate change means to me a decrease of rainfall.	3.80	1.436
I believe there has been a decrease in rain compared to the past.	2.65	1.777
I believe that more drought, and other unusual weather events have occurred in recent years.	3.73	1.198
I believe that the dry season in recent years is longer than in the past.	3.68	1.141
Climate change is likely to have a big impact on farmers like me	4.15	1.051
I am sure global warming is taking place.	4.33	.694
I am sure that climate change is happening or has happened.	4.28	.554
Water resources have been reduced (rivers and wells, springs) due to climate change.	4.55	.677
I have seen a decrease in the quality of my crops due to climate change	3.55	1.176
I have seen a decrease in the amount of my crops annually due to climate change.	4.27	.554
I believe that burning system (A method of burning organic for land preparation) contributes to CC	3.37	1.275
I believe that deforestation contributes to CC	3.48	1.320
I received a climate change related training program from governmental agencies.	4.60	.744
We need technical and basic knowledge of CC adaptation and mitigation	4.25	.630
We have access to the latest agricultural technologies (machinery, irrigation system, etc.)	2.58	1.852
We have strong communication with related stakeholders	3.43	1.083
We Know and learned how to implement climate smart agriculture (any practices to increase income, crop quantity, adaptation and mitigation to CC).	2.83	1.259

4.3.3. Farmers Responses to Climate Change

4.3.3.1. Adaptation to Climate Change

Farmers are experiencing adverse impacts from the changing climate. Explicitly, temperature rise and rainfall variation (Figure 4.11). Table 4.9 Findings also indicate that they felt decreases in crop quality and quantity in their farms. Although adaptation to climate change depends on vast sources of information and the latest technology (Klein 2011), farmers practice adaptation measures based on their indigenous knowledge. Rice is the main agricultural crop in Indonesia, Where adaptation to climate change can enhance the rice sufficiency among smallholder farmers (Candradijaya 2015). The majority of Indonesian farmers are applying adaptations due to crop failure. Figure 4.12 presents that smallholder farmers are practicing the adaptation measure through their experiences and local knowledge. Shifting of plantation dates due to seasonal changes, diversifying into a new crop due to crop failure, and crop varieties to enhance soil fertilization and getting the desired income have been identified as the leading adaptation practices among smallholder farmers. Most of this knowledge comes from their background and historical record in agriculture activities. Candradijaya *et al* (2014), concluded that adaptation among smallholder farmers such as shifting planting time and irrigation scheduling can brings down the level of climate change-induced yield reduction in rice. Usage of manure and compost, changing the time of chemical input, changing the amount of chemical, and practicing water-smart/rainwater harvest technologies were also adaptations as indicative to farmer's adaptive capacity. According to Rozaki (2017), water harvest adaptation technology is the initial alternative for crop plantation at the beginning of the rainy season. As rainfall is the primary source of water for irrigation, access to regular rainfall at the start of the wet season is probably a chance. Kusumasari (2016) stated that farmers had conducted changes in planting patterns, soil cultivation techniques, plant pest control (OPT), and watering techniques due to the limited water supply for agriculture in Indonesia. Findings indicate farmer's interest in organic fertilization instead of chemical input on their farms. Thus, compost consumption among farmers is increasing over time.

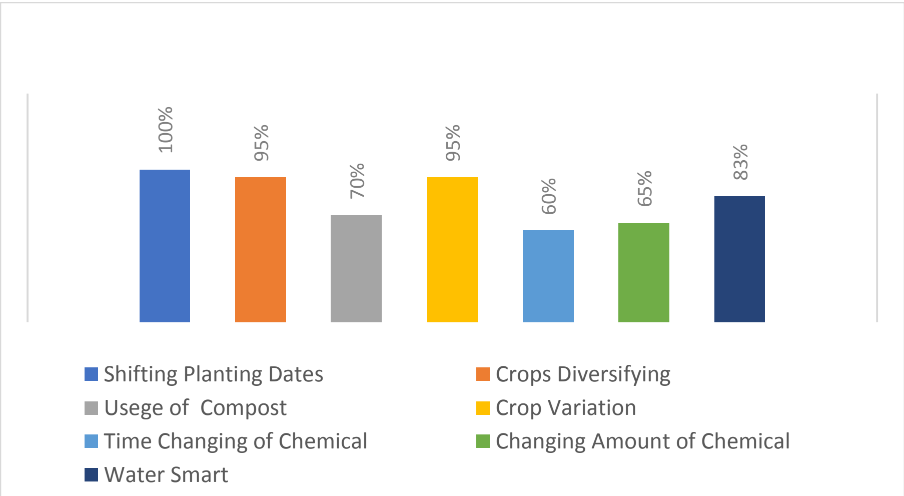

Figure 4.12. Farmers adaptation measures toward climate change.

4.3.3.2. Mitigation to Climate change

Widely, smallholder farmers are dealing traditionally with climate change. Despite farmers not being familiar with the academic word of mitigation, they play a significant role in mitigating climate change in the agriculture sector. A more significant part of farmers supports land-use conservation, forest conservation, and agroforestry, where they believe that forests could recharge groundwater. However, farmers don't have access to the latest agricultural technologies, but the organic farming method is growing faster among smallholder farmers. Moreover, soil organic matter protection, biological pest control technology, and Bio-organic fertilizer mitigation measures have been practiced among farmers (Figure 4.13). A considerable number of farmers are applying the burning method for land preparation, but 38% of respondents are willing to prepare the land without a burning system. Related agricultural agencies have introduced a vital part of these mitigation measures for farmer's knowledge enhancement. The chi-square test result indicates a significant association between climate change perception and land-use conservation measures ($\chi 2=27.179$, df=3, and P=.000). Finding is supported by Surahman, Shivakoti and Soni (2019), they expressed that, most of farmers in the island of Kalimantan are mitigating climate change through land preparation, water management, and soil management or soil conservation.

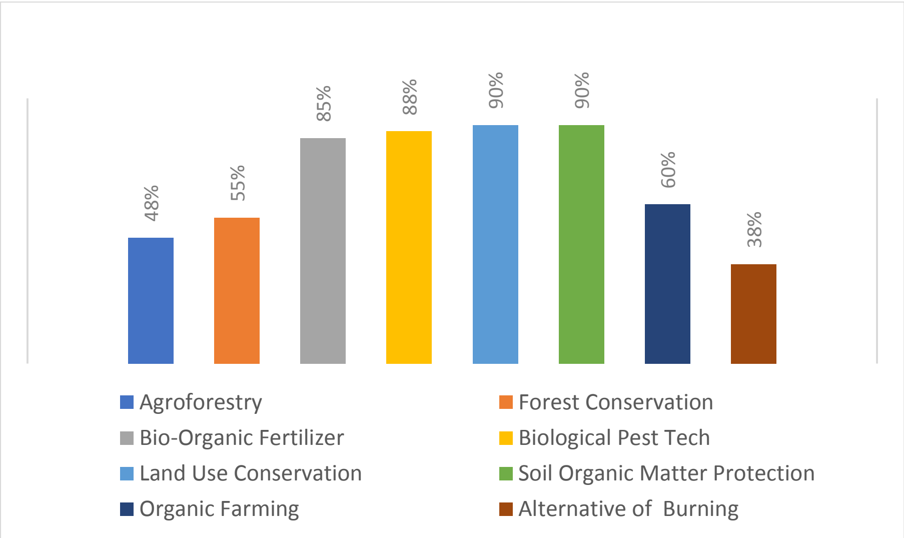

Figure 4.13. Farmers mitigation measures toward climate change.

V CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This study observed greater climatic and land cover changes, including temperature rise, rainfall variation. Overall temperature is rising, and rainfall has the highest variation in July and lowest in November. The present study has been proven that there are no significant trends statistically in annual and seasonal mean rainfall in 1990-2019. Although the linear model of annual and seasonal rainfall displays significant variation and a slight decline since 1990. The last ten years (2010-2019) are assumed to be the warmest decade since 1990. Significant increasing trends have been detected for the annual mean and maximum temperature except for the annual minimum temperature.

Moreover, a total 121,604 Ha area has been changed in Bogor regency since 2000 -2020, where Bogor regency covers almost 266,385 Ha area (BPS-Statistics of Bogor 2020). In particular, significant areas in Bogor converted from vegetation – Agriculture (+27.2%), Vegetation – Built-up (+12.1%), Vegetation – Bare land (+9.6%), forest-agriculture (+9.7%), and Forest – built up (+4.8%). These changes have been occurred due to human activities and their daily demand for development. Approximately 688 Ha land cover has been changed in Dramaga Sub-district in the past 20 years, where Dramaga Sub-district covers 2,437 Ha area in total (BPS-Statistics of Bogor 2020). A great part of the area in Dramaga has been converted into agriculture/cultivated land. Nearly 24% of vegetation land has been changed into agriculture. Moreover, 10.8% of vegetation converted into the built-up area as well.

Smallholder farmers are the key group who faces with pressures of temperature rise and natural hazards, as some consequences of changing climate and rapid land-use changes. This research also highlighted that the climate change perception level is various among farmers. The majority of farmers were aware of climate change, where they felt that climate is changing. Farmers believe that the dry season is getting longer, and crop quality and quantity have been declined. Chi-square test indicated an association between climate change perception and gender, and climate change perception and education level. While adaptation to climate change relies on a great source of information and technology (Klein 2011), but significant population of farmers is dealing with changing climate through some adaptation measures such as shifting of plantation dates, diversifying into a new crop, usage of manure, and compost, crop variation, changing the time of chemical input, changing the amount of chemical, and practicing water-smart/rainwater harvest. In the meantime, some mitigation measures are practiced among farmers as well. Explicitly land use conservation, soil organic matter protection, biological pest control technology, bio-organic fertilizer, organic farming, forest conservation, agroforestry, and alternative burning system in land preparation identified as the primary mitigation measure. A Chi-Square positive association detected between climate change perception and land-use change conservation among farmers.

5.2 Recommendations

Based on the study findings, the study recommends the following measures:

- Decision-makers may develop climate-smart agricultural projects at the community level; This would support creating appropriate environmentally sustainable self-sufficient agriculture at the community level.
- Particularly, to mitigate climate change based on small farming agriculture, relevant stakeholders, including governmental bodies, need to be conducted to provide an alternative for replacing the burning system during land preparation; this measure can be done by providing organic fertilizer and less carbon emission. For instance, introducing the bio-char method might be the critical measure of carbon emissions reduction among smallholder farmers.
- Relevant stakeholders must understand the land cover changes, trends, and future challenges by conducting further prediction studies, to prevent illegal development activities based on governmental regulation and sustainable land use management at the community level, where rapid land cover changes would enhance the community's vulnerabilities and contribute to climate change.
- Decision-makers must reduce farmers' vulnerabilities and enhance their capacity due to a lack of access to the latest environmentally sustainable agricultural technology.

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