RICE CULTIVATION, WEATHER VARIATION, AND IRRIGATION IN INDONESIA

A panel data analysis on the impact of weather variation and irrigation on rice farming in Indonesia

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Abstract

Global food demand is rising as a result of the increasing global population and economic development around the world. At the same time, climate change increasingly puts pressure on global food production. In this context, measures enhancing the climate resilience of farms are required, especially in developing countries. Irrigation is one of these measures, mainly because it helps in dealing with weather vagaries and seasonal rainfall fluctuations. However, climate change also declines the effectiveness of irrigation in terms of dealing with such weather variations. Therefore, research on this topic is important. This thesis contributes to the growing literature on the impact of weather variation on agricultural output and how this impact can be mitigated by investigating the extent to which irrigation programs have enhanced resilience of rice cultivation in response to rainfall shocks in Indonesia between 1968-2000. First, a literature review was carried out to examine relevant types of weather variation and investigate different types of irrigation systems as well as the size of these systems. This resulted in the construction of multiple rainfall variation and irrigation variables, which were included in a number of panel data regression models. The first regression results showed that, in terms of weather variation, only a negative rainfall shock during the growing season of rice had a significant (negative) impact on the Indonesian rice production. The second model estimated that, without including the impact of weather variation, irrigation programs had a positive significant impact on the rice production in Indonesia. The final analysis showed that, by interacting irrigation with the rainfall shock, irrigation programs have not enhanced the resilience of rice cultivation in terms of weather variation in Indonesia. From the interpretation of these results, it can be concluded that, in general, rice cultivation in Indonesia was not generally significantly much affected by rainfall variations. Also, irrigation programs had a positive impact on the rice production. However, this is not the case during the occurrence of a negative rainfall shock, since the final regression indicated that an increase of the irrigation program coverage led to a decrease of rice production during a negative rainfall shock. In other words, the rice cultivation in provinces with a larger irrigation program coverage a more sensitive to a negative rainfall shock. This shows that the Indonesian irrigation systems are not an effective means to reduce the impact of weather variation on food production.

Acknowledgements

This thesis is a final product of a seven-month research project and conducting the research has been a meaningful process. The research brings together subjects I have come to find really interesting: climate adaptation and mitigation and environmental economics. During the research, I have been able to apply much of what I have learnt over the last few years on these subjects to this research, but I also have been able to learn many new things for which I am very grateful. I therefore want to thank several people who greatly helped me throughout the process.

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1. Introduction

1.1 Problem statement and relevance

Global population size has increased rapidly during the last 30 years from 5 billion to almost 8 billion. On top of that, it is estimated that global population will almost reach 11 billion people at the end of the 21st century (Dong et al., 2018; Maja & Ayano, 2021). At the same time, rapid urbanization and industrialization has led to economic development around the world with an annual economic growth of 2.7% during the last 30 years (Dong et al., 2018). This rapid population growth combined with economic development has already led to an enormous rise of the global food demand, and this trend is likely to continue in the future (Maja & Ayano, 2021). It is estimated that more than a 100% increase in food production is necessary to meet the global crop demand in 2050 (Hunter et al., 2017). Meeting this demand is going to be a huge challenge, especially because of the increasing amount of pressure put on the global food production due to climate change (Rondhi et al., 2019). According to the latest IPCC report (IPCC, 2022), the maximum desirable global warming of 1.5 °C is expected to already be reached within the next two decades. Surpassing this will cause an increase of climate-related hazards like heavy rainfall, long periods of drought and rising sea levels, which negatively impacts the food production (IPCC, 2022). Estimations are that an increase of 1 °C in global mean temperature leads to a 3.1%-7.4% decrease in global crop yield (Zhao et al., 2017). Measures that reduce the impact of the increasing global temperatures on crop yield are therefore required.

Regions where population size is most rapidly increasing are also the places that are most vulnerable to climate change (Hossain et al., 2016; Maja & Ayano, 2021). The majority of the farmers in these regions is often poor and therefore less adaptable, due to the limited availability of adaptation instruments (Mase et al., 2017; Mendelsohn, 2008). However, to meet the global food demand, attempts to adapt and mitigate to increase climate resilience of farms in developing countries are of great importance (Rondhi et al., 2019; Ward, 2022). Numerous measures to enhance the resilience of irrigated agriculture to the changing climate are already available (Ward, 2022), such as crop insurance (Bowman & Zilberman, 2013; Falco et al., 2014; Fleckenstein et al., 2020), expanded storage capacity

(Gohar et al., 2013; Gonzalez et al., 2020; Goor et al., 2010) and supplemental irrigation (Chukalla et al., 2015; Rey et al., 2015; Rockstrom et al., 2007). However, successful implementation of these measures still remains a huge challenge due to low capacity, involvement of multiple stakeholders on various levels and the uncertain future of the climate (Varela-Ortega, 2016; Ward, 2022). This indicates that research on this topic is still needed.

One country that is amongst the most vulnerable to the impacts of climate change is Indonesia (Rondhi et al., 2019). Weather shocks such as floods, heatwaves and droughts afflict Indonesia more frequently and have a negative impact on the economic development of the country (Measey, 2010). The agricultural sector constitutes an important part of the Indonesian economy, as it represents 14% of the Gross Domestic Product (GDP) and 60% of the poor rely on agriculture for their income. Rice is the main crop produced in Indonesia (Statista, 2022) and 95% of the national rice production relies on irrigated agriculture (World Bank, 2022). Rice production is of major importance for Indonesia since it helps with increasing food security and reduce poverty across the country (Pattanayak & Kumar, 2014). This is potentially problematic as rice production is sensitive to climatic factors, and therefore vulnerable to climate change (Pattanayak & Kumar, 2014). Thus, adaptation and mitigation strategies to enhance climate resilience of rice farmers in Indonesia are required (Rondhi et al., 2019).

Indonesia has a long history of investment in irrigation projects, originating in the middle of the 19th century as a response to a long period of severe drought (Pasandaran, 2010). Large scale investments between 1900 and the end of the colonial period led to an increase of the total irrigated area from about one million hectares to 3.5 million hectares (Burger, 1975). Most of the new irrigation systems were located on Java and investments in irrigation systems were considered an important policy instrument to increase welfare (Pasandaran, 2010). A second wave of large-scale investments in irrigation systems started after the colonial period, with the aim to address the problem of food insecurity and as a response to the green revolution during the 1960s (Pasandaran, 2010). During the 1970s, Indonesia's state budget ballooned due to an enormous rise of the oil price. This money was utilized for investments in irrigation systems and to achieve rice self-sufficiency (Houterman et al., 2004; Pasandaran, 2010). Besides this, other countries and multiple international agencies helped the Indonesian Government with the construction and improvement of the irrigation systems, with the World Bank as the main investor (Booth, 1977). These large-scale investments in irrigation and agricultural development led to a 4.8% annual increase of rice production between 1969 and 1989 and rice self-sufficiency was achieved in 1984 (Pasandaran, 2010; Vermillion, 2011). Despite these successes, not all irrigation projects succeeded, mostly because attention towards operation and maintenance after the implementation of irrigation systems was often missing (Houterman et al., 2004; Pasandaran, 2010).

Irrigated agriculture makes it possible to deal with weather vagaries and seasonal rainfall fluctuations and can therefore help to improve climate resilience for rice production in Indonesia (Angelakis et al., 2020; Auffhammer & Schlenker, 2014; Dell et al., 2014). However, as shown in the previous paragraph, not all irrigation projects succeed and are therefore not always successful in enhancing climate resilience of agriculture. Besides this, enhancing climate resilience of irrigated agriculture is increasingly becoming challenging due to climate change (Ward, 2022). Therefore, identifying to what extent irrigation infrastructure helps with mitigating the impacts of weather variations can aid in the effective design of future policies and institutions (Dell et al., 2014). Substantial research that estimates the impact of weather variation on rice production has already been conducted. Almost all recent studies on this topic use panel data models, since this method also takes non-climatic variables (such as irrigation) into account (Blanc & Schlenker, 2017). These studies use many diverse types of weather variations in their models, varying between inter-annual differences and so-called 'weather shocks', which represents a chosen deviation from the mean (Dell et al., 2014). Following these studies and the increasingly growing challenge of enhancing the climate resilience of irrigated agriculture (Ward, 2022), this study aims to contribute to this by examining a possible relationship between rice production and weather variation in Indonesia between 1968 and 2000 and, if existent, to what extend this relationship has been mitigated by irrigation infrastructure. More specifically, the relative sensitivity of rice harvest to rainfall variability, together with the impact of irrigation infrastructure on this sensitivity, is assessed.

1.2 Objectives and research questions

This study aims to estimate to what extent irrigation infrastructure enhances resilience of rice cultivation in terms of weather variation in Indonesia between 1968-2000. The sub-objectives of this study are:

1. *Identifying what different irrigation programs have been implemented in Indonesia between 1968-2000 and what these programs look like.*
2. *Estimating the impact of different types of weather variation on rice output in Indonesia between 1968-2000.*
3. *Estimating the impact of irrigation systems on rice output in Indonesia between 1968-2000.*

Following from the main objective and corresponding sub-objectives, the main research question is:

To what extent have irrigation programs enhanced resilience of rice cultivation in terms of weather variation in Indonesia between 1968-2000?

To be able to answer this research question, it is substantiated by the following sub-questions:

1. *What different irrigation programs have been implemented in Indonesia between 1968-2000 and what do these programs look like?*
2. *What is the impact of weather variation on agricultural output in Indonesia between 1968-2000?*
3. *What is the impact of irrigation systems on the agricultural output in Indonesia between 1968-2000?*

A literature review provides insights into the implemented irrigation programs in Indonesia between 1968-2000 (SQ1) and into relevant types of weather variation concerning Indonesia. These first steps make it possible to construct relevant variables, which are used in the statistical analysis of this research to estimate the impact of weather variations (SQ2) and the impact of irrigation programs (SQ3) on the Indonesian rice production. The final regression analysis, which includes both weather variation and irrigation variables, is used to determine to what extent irrigation programs have enhanced the resilience of rice cultivation in Indonesia (RQ).

1.3 Outline of the report

The thesis is structured as follows. First, chapter 2 provides a general overview of studies that have investigated the impact of climate on agricultural production, followed by an overview of the Indonesian climate and rice cultivation in Indonesia. Then, chapter 3 provides an historical overview of irrigation development in Indonesia, as well as a presentation of a typical Indonesian irrigation scheme, which serves to answer the first sub-question. Chapter 4 provides an overview of all acquired data along with an explanation on the used method. The results are presented in chapter 5, and the interpretation and implications of these results are provided in Chapter 6. This chapter also includes the limitations as well as suggestions for further research. The study is summarized and concluded in chapter 7.

2. Climate and agricultural production

This chapter provides a better insight into the theoretical impact of weather on agricultural production. The first part presents a general overview on the topic. The second part discusses more case-specific topics which includes (1) a description of the Indonesian climate and (2) an explanation of rice cultivation in Indonesia and existing knowledge of the impact of weather on rice cultivation. The information in this chapter is used for the construction of relevant weather variation variables, which are presented later in the thesis.

2.1 General overview

There is a growing body of academic research that examines the impact of climatic factors (e.g., weather fluctuations) on agricultural output. A large share of the literature uses statistical models to estimate relationships between weather variables and crop yield (Blanc & Schlenker, 2017; Dell et al., 2014; Pattanayak & Kumar, 2014). These models have evolved much over time, not only by applying different scales and time-periods, but more importantly by including the treatment of different weather variables (Lobell & Burke, 2010). Earlier studies based estimations on crop-weather relationships solely on annual weather averages (e.g., Nicholls, 1997), while later statistical models started to provide more specific estimates by following crop science more closely (Roberts et al., 2013) and by transforming weather measures in line with agronomic studies (Deschênes & Greenstone, 2007; Schlenker & Roberts, 2006). These models use additional weather variables (e.g., maximum or minimum precipitation) based on the studied location and crop to provide more precise estimations (Auffhammer et al., 2006; Lobell, 2007; Lobell & Field, 2007; Welch et al., 2010). Additionally, studies started to consider the growing seasons of crops as an important time frame instead of the calendar year (Lobell & Asner, 2003; Auffhammer et al., 2006; Lobell, 2007). To gain a better understanding on the impact of climatic factors on agricultural output, a brief overview of studies that estimate this is provided in the remainder of this paragraph. This overview consists of studies that examine the impact of temperature variation on different crops as well as studies that examine the impact of rainfall variation on different crops. However, the main focus is on the latter since this is most relevant to this study.

The influence of temperature on agricultural output has been investigated in numerous studies. In general, statistical studies show a clear negative impact of hotter annual temperatures on agricultural output when the temperature increase exceeds a crop-specific threshold (Dell et al., 2014; Malhi et al., 2021). Schlenker and Roberts (2009) conducted a study on the critical threshold temperatures for corn, soybeans and, cotton and estimated that yield rapidly decreases when these temperatures are surpassed. Schlenker and Lobell (2010) concluded that in sub-Saharan Africa higher temperatures negatively impact crop yield by using a panel model. A study of Roberts et al. (2013) on the impact of weather variation on corn yield in the United States found that an increase in temperature decreases corn yield. Other research on the impact of temperature on agricultural output conducted by Welch et al., (2010) shows that a higher minimum temperature reduces crop yield. For their research, they exploited a panel dataset on rice farms in multiple Asians countries. Another study on rice by Pattanayak and Kumar (2014) came to a similar result. They estimated that in India, higher day temperatures had a negative impact on rice yield.

Similar research has been conducted to examine the impact of rainfall variation on agricultural output. However, while studies that estimate the impact of temperature on crop yield commonly employ annual time scales (Dell et al., 2014), this is not the norm for studies that estimate the impact of rainfall on agricultural output. These studies often look at monthly or even daily rainfall variables and are therefore more diverse. In addition to this, contradictory to the impact of temperature on agricultural output, both rainfall increases and decreases can impact agricultural output. Levine and Yang's (2014) study provides an example of how total annual rainfall variation can impact agricultural output. They examined the impact of total annual precipitation, instead of temperature, on rice yield by using a panel of Indonesia districts and found out that more annual rainfall leads to a higher production of rice. Kar and Kar (2008) also investigated the impact of precipitation on crop yield on an annual timescale. They concluded that in Odisha (India), crop yield was lower in years with relatively low rainfall. A study conducted by Kotz et al. (2022) estimated, in contradiction to the previous two-discussed studies, little to no response of agricultural output to annual rainfall variation. The different types of rainfall variables that they used in their model are extreme daily rainfall, number of wet days, monthly positive and negative rainfall deviations and total annual rainfall. Besides the low response of agricultural output to total annual rainfall changes, they estimated a similar result for the daily rainfall measures. However, their study revealed that agricultural output is strongly impacted by both monthly positive and negative rainfall variations. Agricultural output does increase when monthly rainfall is above the monthly historical mean but decreases when the monthly rainfall is below the historical monthly mean. Studies that have concluded a crop-rainfall relationship of weather variables on a more daily time scale (e.g., extreme weather events) are the studies by Lesk et al. (2016) and Auffhammer et al. (2012). Lesk et al. (2016) investigated the impact of extreme weather events on crop yield on a global scale and displayed that droughts systematically reduce crop yield. Auffhammer et al. (2012) conducted research on the impact of multiple weather variables (i.e., total seasonal rainfall, drought, extreme rainfall, solar radiation, and minimum temperature) on rice yield in India. Their model showed that both extreme drought and extreme rainfall has a serious negative impact on rice yield. Another noteworthy conclusion is from a literature review by Dell et al. (2014), who found that the relationship between the impact of rainfall variations on crop yield is much more present in developing countries due to lower levels of functional irrigation in these countries compared to developed countries.

As mentioned in the first paragraph of this chapter, the growing season of a crop is often used as time frame instead of the usual calendar year. This especially holds for studies on rice production since the timing of the start of the wet season has a big influence on the annual rice production (Naylor et al., 2007). In general, rice is more influenced by rainfall compared to other main crops, since it needs a minimum amount of rainfall to grow (Yoshida, 1981). Examples of studies that have applied this are the earlier discussed studies by Levine and Yang (2014) and Auffhammer et al. (2012). Also, a study by Roberts et al. (2013) showed that the impact of precipitation changes is very weak for other main crops (i.e., corn and maize), mainly because these crops grow in places with sufficient rainfall. The study by Naylor et al. (2007) on the impact of delayed rainfall caused by El Niño–Southern Oscillation (ENSO) on rice production in Indonesia estimated that this delayed rainfall negatively influences the Indonesian rice production. Studies by Dhamira and Irham (2020), Santoso et al. (2016) and Tan Yen et al. (2019) also concluded, similar to Naylor et al. (2007), that inter-annual rainfall variations caused by ENSO dynamics negatively impact Indonesian rice output.

In conclusion, literature has estimated a clear relationship between agricultural output and weather variations. While the influence of temperature on agricultural mostly occurs by a temperature increase, this is different for precipitation variables. Both an increase and a decrease in precipitation, differing from extreme events, monthly precipitation and annual precipitation can influence agricultural output. The literature also shows differences between crops, as rice is much more influenced by rainfall variability compared to other main crops. In the next paragraph, a more case-specific explanation of the impact on weather variables on agricultural output is provided.

2.2 Impact of rainfall on rice output in Indonesia

2.2.1 Indonesian climate

As described above, a lot of research that investigates the impact of weather variables on agricultural production has been conducted. While most studies discuss both temperature and precipitation variables, this study only discusses precipitation (more specifically rainfall) variables. Indonesia is located astride the equator and therefore knows little variations in temperature, both over years as across the country (Levine & Yang, 2014). By contrast, rainfall varies much both across the different Indonesian provinces and over the years. This annual and inter-annual rainfall variation is mainly caused by the Austral-Asia monsoons and in some years by ENSO dynamics and is the primary determent of year-to-year differences in Indonesian rice output (Naylor et al., 2001). Additionally, clear links between rainfall and agricultural output have already been proven (Naylor et al., 2007).

The impact of monsoons and ENSO dynamics on the Indonesian climate varies between different regions of Indonesia because of its enormous size and because Indonesia is located between the Pacific and Indian Oceans. A study on the different climates of Indonesia by Aldrian and Dwi Susanto (2003) displays that Indonesia can be divided into three distinct climate sub-regions. They based this division on monthly rainfall variation patterns, and the three different regions are shown in Figure 1 below. Region A (red) covers the largest area, and the rainfall pattern of this region is therefore the dominant pattern of Indonesia. This region is the monsoonal region and is characterized by a mean peak rainfall during December-February. The dry season is during June-August. Region B (green) can be defined as the semi-monsoonal region. This region covers mostly the Western part of Indonesia and exhibits two peaks of mean rainfall over the year: one around March-May and one around October-December. Region C (blue) can be defined as the anti-monsoonal region, and the annual mean rainfall patterns is the opposite of the pattern of region A. This means that the wet season of this region occurs during the drier seasons of the other two regions. The monthly rainfall variations for the period 1950-1998 of the distinctive regions are depicted in Figure 2 below.

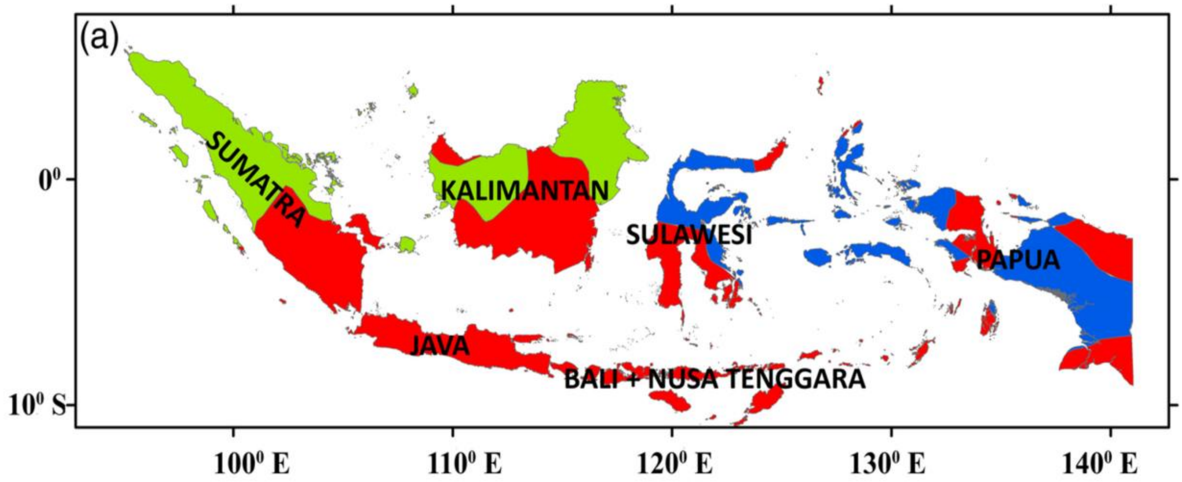
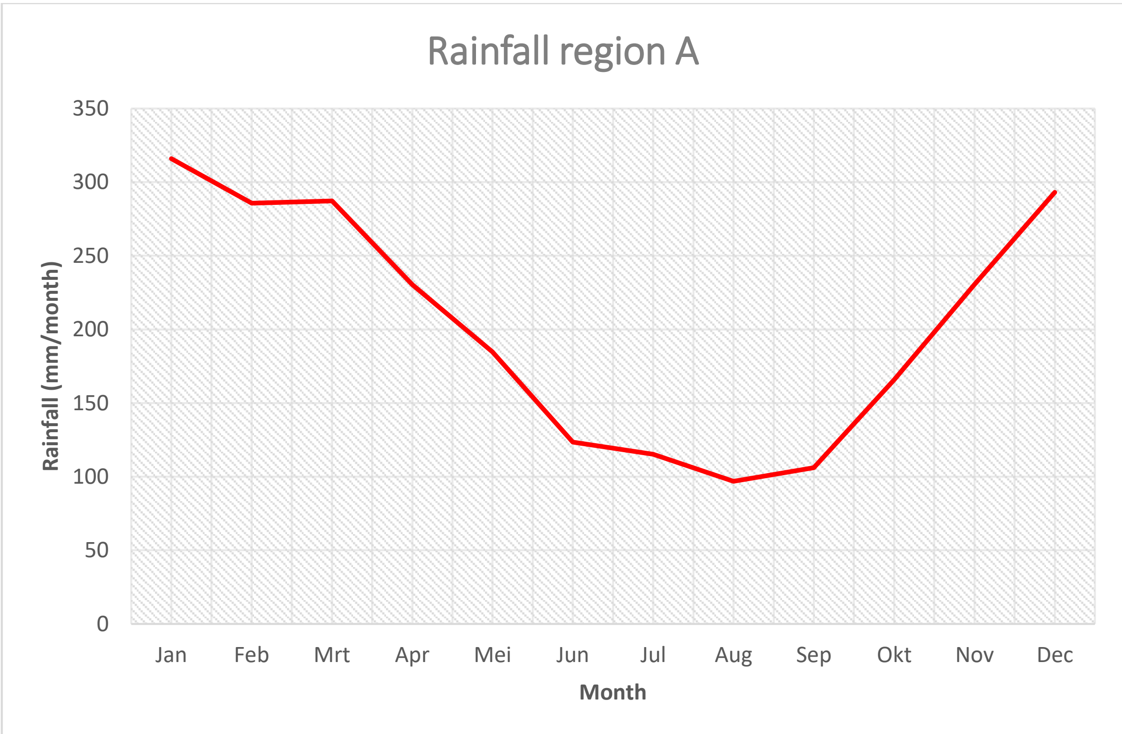
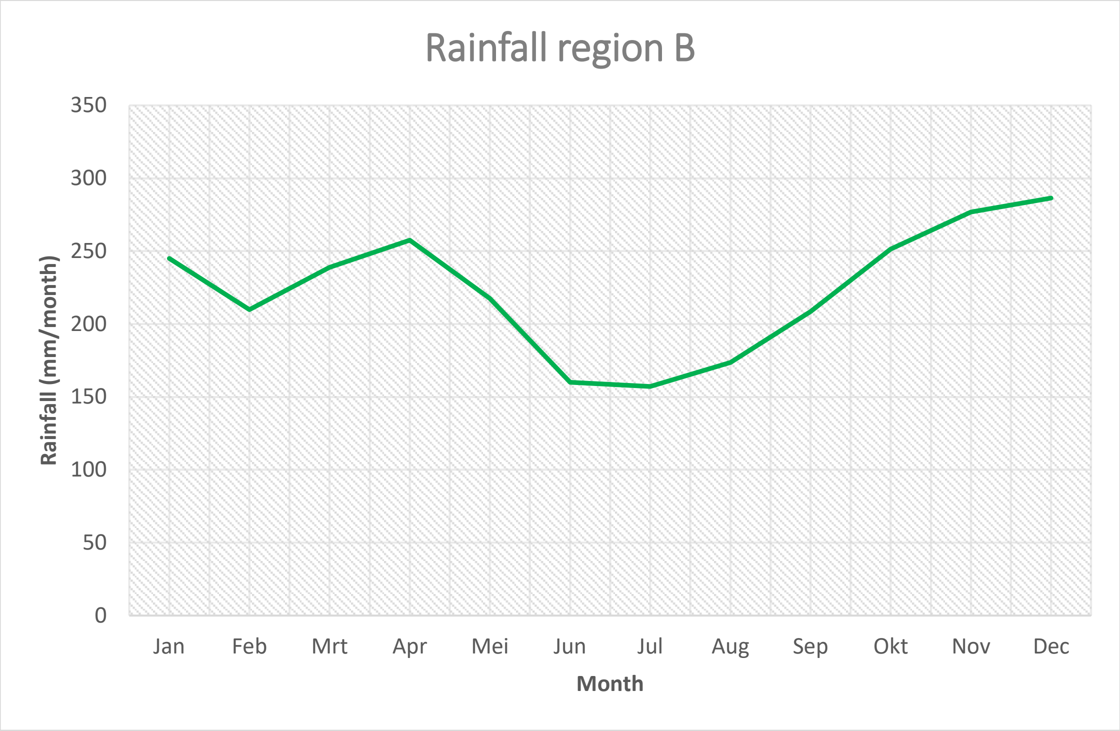


Figure 1: Map with the three climate sub-regions of Indonesia with Region A (red) as the monsoonal region, Region B (green) as the semi-monsoonal region, and Region C (blue) as the anti-monsoonal region. Source: Kurniadi et al. (2021).





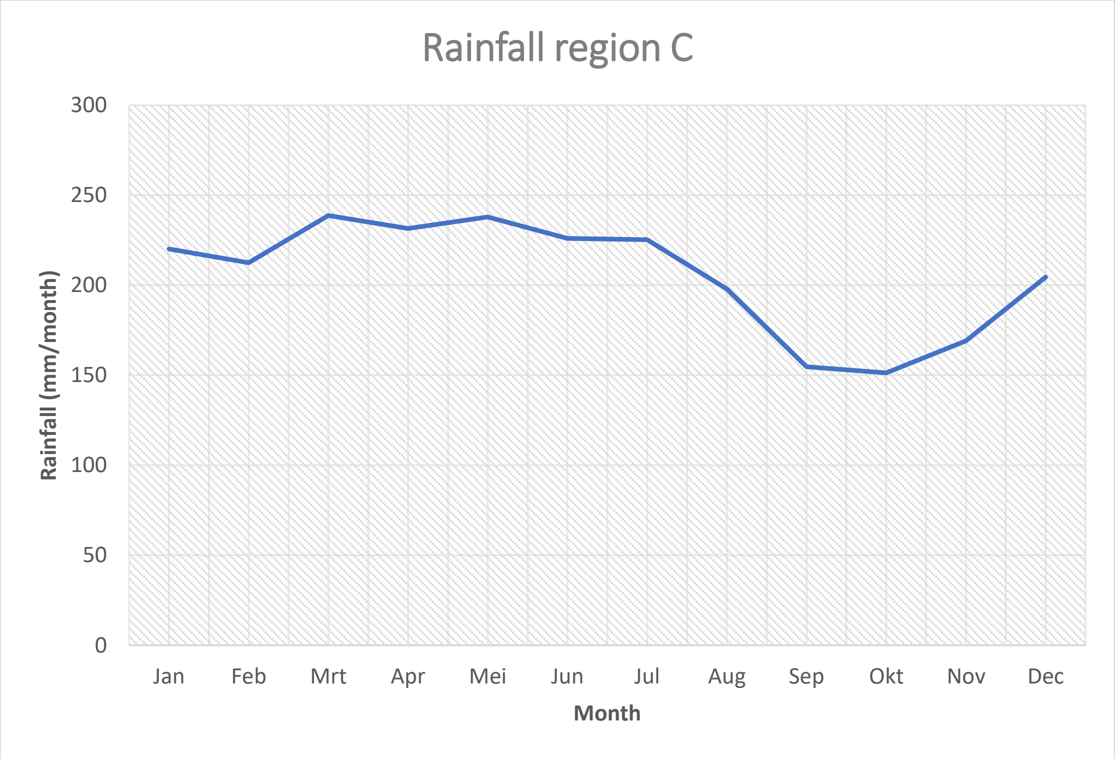


Figure 2: Average annual rainfall cycles of the three distinctive climate regions for the period 1950-1998. The gridded precipitation dataset from Harris et al. (2020) is used for the construction of the figures. The period 1950-1998 is chosen since this period is also used by Aldrian and Dwi Susanto (2003) for the determination of the three different climate zones.

ENSO dynamics, which occur within every two to seven years, have a big influence on inter-annual climate variations in South-East Asia, and therefore in Indonesia as well. ENSO is especially related to high variations in precipitation (Boer & Suharnoto, 2012; Ismail & Chan, 2020; Naylor et al. 2001; Surmaini et al., 2015) and causes the occurrence of extreme weather events such as droughts and floods (Boer & Suharnoto, 2012; Ismail & Chan, 2020; Surmaini et al., 2015). ENSO can be categorized into the following two phenomena: El Niño and La Niña. In general, the occurrence of La Niña causes an increase in precipitation, temperature and the occurrence of floods (Ismail & Chan, 2020), while El Niño leads to a decrease in precipitation, temperature and the occurrence of droughts (Boer & Suharnoto, 2012; Ismail & Chan, 2020; Surmaini et al., 2015). In the past, El Niño has led to natural disasters in Indonesia in the form of extreme low water levels (Boer & Suharnoto, 2012; Naylor et al. 2001; Surmaini et al., 2015) and forest fires (Ismail & Chan, 2020), and expectations are that this will only increase in the future (Shean, 2014). The impact of El Niño on temperature and precipitation is dependent on the intensity of El Niño, which differs each time. Table 1 provides an overview of all the El Niño events within the period 1950-2000 along with the intensities of each event. The intensity of each event is based on the impact that it has on precipitation and temperature tresholds. Another important aspect of El Niño is that it can delay the start of the wet season, which can have big consequences on the Indonesian rice production (Naylor et al., 2002, 2007).

Table 1: El Niño intensities for the period 1950-2000. Source: Ismail & Chan (2020)

Weak	**Moderate**	**Strong**	**Very Strong**
1951-52	1963-64	1957-58	1982-83
1952-53	1986-87	1965-66	1997-98
1953-54	1987-88	1972-73	
1958-59	1991-92		
1968-69			
1969-70			
1976-77			
1977-78			
1979-80			
1994-95			

2.2.2 Rice cultivation in Indonesia and the influence of rainfall variation

Rice cultivation in Indonesia mainly takes place on Java, Sumatra, South Sulawesi, Bali and Nusa Tenggara (Dhamira & Irham, 2020; Naylor, 2007). Figure 1 shows that these areas are mainly located within the monsoonal region (in red), which is characterized by a wet season generally starting around October-November (Figure 2). Rice cultivation in Indonesia is heavily dependent on the start of this season as this process involves farmers growing seedlings in small wet plots and subsequently transferring the seedlings to the wet paddy fields at the start of the wet season when rainfall is sufficient (Skoufias et al., 2012). In general, rainfall is sufficient when it reaches 20 centimetres which usually happens around September-October (Naylor et al., 2002). After planting, rice plants need 3 to 4 months to grow before the rice can be harvested and 60-120 centimetres of rainfall is needed during this grow-out period (Naylor et al., 2002). The exact amount of necessary rainfall is dependent on the agroecosystem, irrigation, and the timing of the rainfall (De Datta, 1981). After harvesting of wet season rice, a smaller dry season planting takes place around April-May (Naylor et al., 2007).

Planting dates of rice are therefore of great importance for rice production in Indonesia, and the timing of the planting is the best reflector of the impact of rainfall on the rice production (Naylor et al., 2002). As mentioned earlier, the occurrence of El Niño delays the start of the wet season and therefore negatively affects rice production in Indonesia in two different ways (Naylor et al., 2001, 2002, 2007). At first, delayed rainfall during the wet season causes the rice crop to be planted later, since this needs 20 centimetres of rainfall. This extends the "hungry season," which is the season before the harvest of the wet-season rice (Naylor et al., 2002, 2007; Skoufias et al., 2012). At second, delayed planting of the rice during the wet-season in turn delays planting of the dry-season rice. This reduces rice area, and thereby leads to a decrease of the total rice production (Naylor et al., 2002, 2007; Skoufias et al., 2012). According to studies by Ismail and Chan (2020) and Surmaini et al (2015), El Niño has a significant impact rice production on when they are labelled as 'moderate', 'strong' or 'very strong'. This impact can differ per El Niño, depending on when they are able to detect the occurrence of an El Niño event. There are cases of events that were labelled as 'strong' or 'very strong' which did not significantly impact rice production in Indonesia. This is because the occurrence of El Niño's was already detected in early spring and rice farmers were therefore able to adapt to the upcoming drought a delayed start of the wet season (Surmaini et al., 2015).

Thus, the main driver for paddy production is climate, since it needs a minimum amount precipitation to be able to grow. Literature shows that precipitation variations can negatively impact Indonesian rice production and are therefore crucial to investigate. During El Niño years, variations in precipitation are much more present. The occurrence of El Niño has therefore often a negative impact on rice production. The literature discussed in this chapter provides a starting point to scrutinize the influence of different types of rainfall variation on rice cultivation in Indonesia in the remainder of this thesis.

3. Irrigation in Indonesia

Besides the influence of climatic factors, rice cultivation is also impacted by other aspects such as irrigation. Irrigated agriculture is of importance for many societies around the world and has been around for millennia. Irrigation is the process where water is transferred from rivers, lakes, reservoirs or aquifers through canals, pipes, sprinklers, or any other man-made means to the soil in order to meet the water demand of crops. It enhances quality, reliability, and magnitude of crop production, and contributes to over 40% of global food production (Bjorneberg, 2013). The existence of irrigation helps reducing poverty (Huang et al., 2006; Hussian & Hanjra, 2004; Rizal et al., 2021) and ensuring food security (Carruthers et al., 1997; Darko et al., 2016; Kesuma et al., 2018). Even the presence of the simplest types of irrigation systems present during ancient times helps with assuring food security, especially during the drier seasons (Bagson & Kudder, 2013). Additionally, irrigation systems assist farmers in adapting to climate change (Amede et al., 2014).

The main reason behind the above-mentioned positive aspects of irrigated agriculture is that irrigation systems generally help to deal with variation in rainfall and long periods of drought. Irrigation has caused agricultural production to be less dependent on uncertain rainfall patterns, and this is studied by many (e.g. - Angelakis et al., 2020; Auffhammer & Schlenker, 2014; DuBois et al., 2012; FAO, 2014; Rondhi et al., 2019; Turral et al., 2011). However, to what extent irrigation systems actually mitigate the impact of uncertain rainfall patterns on the agricultural production depends on the type of irrigation (Angelakis et al., 2020). To understand the influence of irrigation systems on rice production in Indonesia and how these could possibly reduce the impact of rainfall on production, it is important to understand what irrigation systems in Indonesia look like and how they operate. Irrigated agriculture has been around for more than 2000 years in Indonesia and has been developed ever since (Pasandaran, 2010). However, it goes beyond the scope of this thesis to go fully into detail on made developments over this period. Therefore, the next paragraph consists of a brief description of developments relevant to the state of the irrigation systems at the beginning of the time period investigated in this thesis. The subsequent paragraphs exist of a description of the irrigation developments in Indonesia during the period 1968-2000 and an overview of a typical Indonesian irrigation scheme. This is done to answer the first sub-question: *What different irrigation programs have been implemented in Indonesia between 1968-2000 and what do these programs look like?* This information is used for the construction of irrigation variable(s) for the regression models and for the interpretation of the regression results.

3.1 Irrigation in Indonesia until the 1960s

Indonesia has a long history of irrigated rice farming. Rice cultivation began in the 16th century BC, while the first irrigation systems were found around the first century AD (Pasandaran, 2010). These first systems were small in size, relatively simple in terms of capacity to distribute and deliver water, and vulnerable to external shocks such as droughts and floods. Despite this, local communities were able to sustain the irrigation systems for generations (Pasandaran, 2010). The start of Dutch colonization at the beginning of the 17th century led to agricultural developments, with high benefits from agricultural products produced in Indonesia as the main goal (Tirtalistyani, 2022). However, the first real efforts of large-scale development were introduced around the mid-19th century as a consequence of a famine in 1849 (Pasandaran, 2010). This famine was caused by a long period of drought, which increased attention of the colonial government to initiate the development of large-scale irrigation infrastructure. The first investments in irrigation were located in Central-Java and East-Java and mostly existed of weirs to support irrigation infrastructure and systems and were completed at the late 19th century (Ravesteijn, 2002).

Around the beginning of the 20th century, irrigation development became one of the instruments for the implementation of the so-called "Ethical Policy". The ethical policy can be referred to as a moral justification of previous political decisions that were invoked on the Indonesian population and negatively affected them (Tirtalistyani, 2022). Irrigation was, together with education and emigration, a policy instrument established to solve the problem of poverty and the declining state of welfare in Java (Booth, 1977). As a result of the adaptation of the ethical policy, large-scale irrigation growth and the formation of government-based irrigation management organizations were possible during the first three decades of this century (Tirtalistyani, 2022). This development led to an increase of total in irrigated area from 2,412,00 ha in 1915 to 3,200,000 ha in 1925 (Booth, 1977, pp. 41). However, while the total amount of irrigated land increased, the average yield remained constant. This does not mean that the irrigation systems did not have any influence on the rice output. In this period, harvested area for rice rapidly increased due to population pressure. A large part of this area consisted of land that was used for other crops before. This might have had a negative impact on yield, since investments made by the colonial government were on irrigation of rice lands and not on irrigation of lands used for production of other crops. These lands were therefore still irrigated by much more primitive means or not irrigated at all (Booth, 1977). So, while the average yield remained constant, there is still a high probability that yield sharply increased on the areas where the irrigation developments had taken place as a result of the ethical policy.

In 1926, irrigation management was decentralized to a provincial level to support agricultural development on a smaller scale (Pasandaran, 2010; Tirtalistyani, 2022). While this should have led to better maintenance and the construction of new irrigation systems, this was not the case in reality. Co-operation between farmers and governmental irrigation officials was difficult, which led to unclarities regarding responsibility for the maintenance of the irrigation systems. Farmers did have the final responsibility, but they were unaware of that. At the end, the decentralization of irrigation management led to poor maintenance of irrigation systems, and new systems were barely constructed (Booth, 1977). According to Ravesteijn and Nispen (2007), this decentralisation was just "a covert way of introducing cutbacks" (pp. 283). This was needed because the period from the

1930s until the 1960s is characterized by multiple economic depressions, which also led to political instability. Decentralization of irrigation management and other consequences of the economic depressions and political instabilities had a big impact on the irrigation schemes later on. Dams were silted up; channels were full of sedimentation and weirs slowly broke down. Plans have been made during the 1950s and the beginning of the 1960s to rehabilitate the existing irrigation infrastructure back its old condition, but evidence available that these plans have actually been properly executed lacks. This has resulted in an extremely poor state of the Indonesian irrigation networks during the 1960s (Booth, 1977).

3.2 Irrigation in Indonesia during the period 1968-2000

In response to green revolution technologies and to address the problem of food insecurity during the 1960s, the government decided to introduce Five-Year Development Plans (Pelita) starting in 1969. Where increasing welfare on Java was the driving force behind the investments into the expansion and development of irrigation systems in the beginning of the 20th century, the driving force behind the introduction of the Pelita's was to achieve rice self-sufficiency (Pasandaran, 2010). As mentioned in the previous paragraph, irrigation systems were not maintained properly until around 1965. This had large negative consequences on the efficiency of irrigation systems. The capacity of the irrigation systems' channels had dropped by more than 50% and water loss during transportation of the water through the irrigation channels was three times above the norm. The implementation of structured plans to improve these systems was therefore highly needed (Booth, 1977).

The introduction of the Pelita's aimed to improve and rehabilitate existing irrigation systems and the construction of new irrigation systems where this was feasible (ICID, n.d.) and this was the main priority during the first four Pelita's (1969-1989). Significant investments were needed for successful implementation of these plans. Worldwide rising oil prices caused an enormous boost of the Indonesian economy, which made it possible for the Indonesian Government to make these investments (Tirtalistyani, 2022). Besides this, a number of international agencies and other countries assisted the Indonesian Government in expanding and improving their irrigation schemes, with The World Bank as the main investor (Booth, 1977). In 1984, the goal of the Indonesian Government to be rice self-sufficient was achieved as a result of public investments in the development of the irrigation sector and the first four Pelita's are therefore often cited as a success (Pasandaran & Zuliasri, 2001).

During the first and second Pelita, the priority of the Indonesian Government was to rehabilitate existing irrigation schemes on Java. Besides this, they also started to focus on constructing new irrigation schemes on Sumatera, however this was not their main priority (ICID, n.d.; Pasandaran, 2010). This changed in the 1980s (third and fourth Pelita) in order to support the development of the less developed regions in Indonesia. The main focus during these Pelita's was to construct new irrigation systems outside Java, while also still working on the rehabilitation of existing irrigation schemes on Java (Pasandaran, 2010). Seventeen rehabilitation programs have been successfully implemented during the first four Pelita's. Every program consisted of one or more different projects, and projects existed mainly of (1) rehabilitation of the irrigation infrastructure of existing irrigation schemes; (2) construction of new irrigation schemes by building channels, dams, reservoirs, or any other type of infrastructure; and (3) assisting farmers by providing them with machinery or knowledge. An overview of the projects from the seventeen rehabilitation programs is shown on the map of Figure 3 below, and in Table 1 of Appendix I. This map depicts the distribution of projects over Indonesia, with most projects located on Java. Besides this, the government started a 'provincial irrigation development program' to decrease the country's dependency on the economic activities on Java. The intention of this program was to construct and improve irrigation networks on Sumatera and Sulawesi and led to the development of a combined 80,000 ha of irrigable area on these islands (World Bank, 1991).

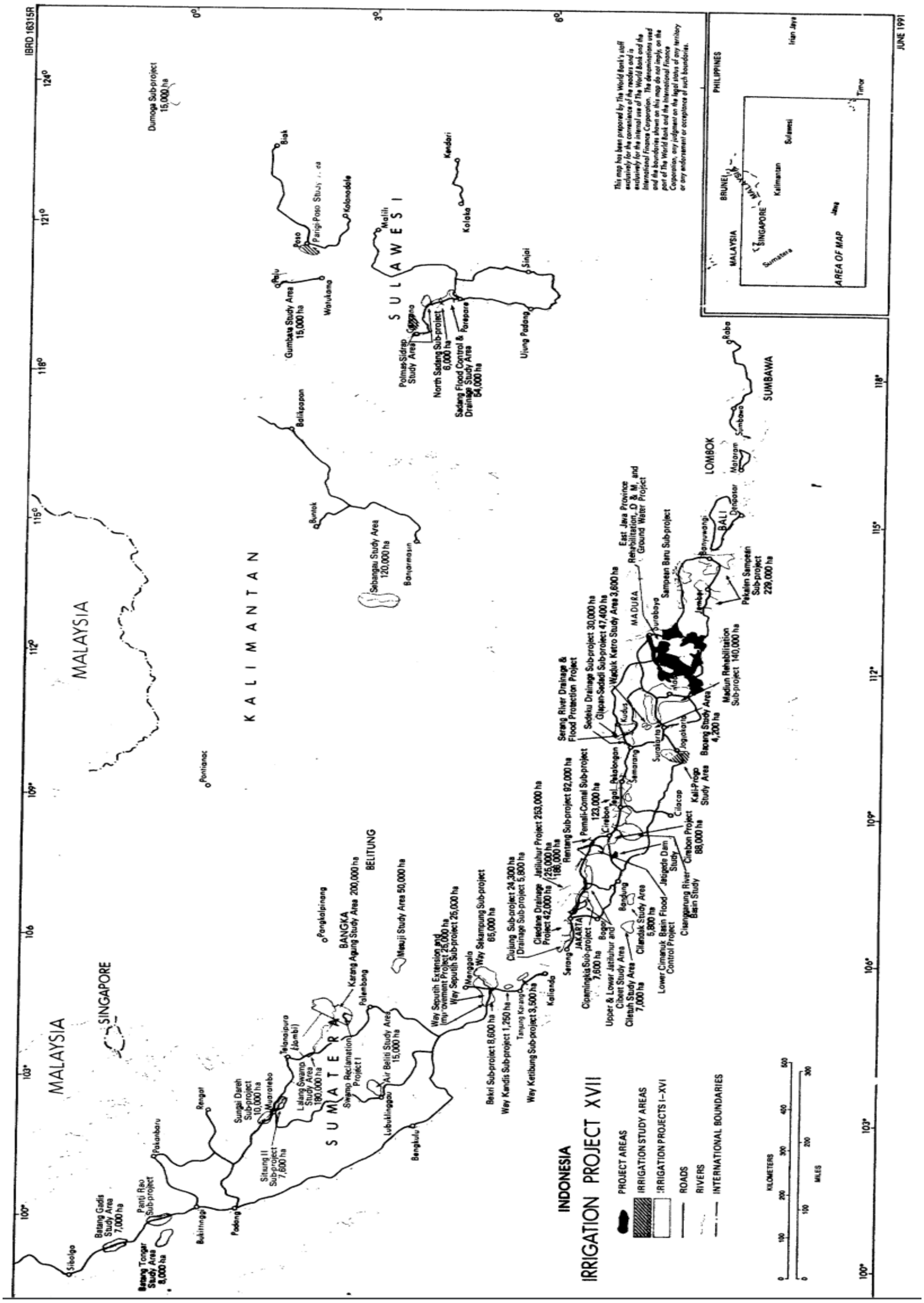


Figure 3: Map of Indonesia with all the projects from the seventeen rehabilitation programs included. Source: World Bank (1991)

The idea of the first rehabilitation program of the Indonesian Government started in 1966 and the last program was finished around 1989. Table 2 below shows the developments that have been made as a result of these programs. Besides the increase of more than 1,000,000 ha of additional irrigated area, many simple irrigation schemes were transformed into semi-technical or technical irrigation schemes. In Indonesia, they distinguish between three different types of irrigation schemes: technical irrigation, semi-technical irrigation and simple irrigation. Technical irrigation schemes are large schemes (≥ 1,000 ha) constructed and operated by governmental agencies and are permanent. Semi-technical are minor schemes (< 1,000 ha) constructed by governmental agencies and operated by the farmers and are either permanent or temporary. Simple irrigation schemes are temporary minor irrigation schemes, which are constructed and operated by farmers (ICID, n.d.).

Table 2: Total irrigation in Indonesia in 1966 and 1989. Source: Gany (1993)

Irrigation scheme	***Year***	**Total (ha)**
Technical	*1966*	1,704,000
	1989	2,701,765
Semi-Technical	*1966*	758,000
	1989	1,271,472
Simple	*1966*	1,335,000
	1989	846,548
Total	*1966*	3,797,000
	1989	4,819,785

Due to the rehabilitation programs, the Indonesian Government took over the control of most of the irrigation schemes, which is also shown by the increase of total technical irrigation schemes. However, this did not have the intended impact. Therefore, during the fifth Pelita (1989-1994), the main priority was to improve operation and maintenance of the existing irrigation schemes which resulted into the formulation of The Irrigation Operation and Maintenance Policy in 1987 (Houterman et al., 2004). The goal of this policy was to make the farmers responsible for the maintenance of the irrigation systems instead of the government, however this policy did not lead to any noticeable changes. The government continued with heavy investing into the rehabilitation and construction of irrigation schemes, which overruled the intentions of The Irrigation Operation and Maintenance Policy (Houterman et al., 2004). During the sixth Pelita, the amount of land equipped for irrigation heavily increased with the construction of 300,000 ha of new irrigation schemes. Besides this, 700,000 ha of irrigation schemes has been rehabilitated within this period (ICID, n.d.).

3.3 Irrigation schemes in Indonesia

Figure 4 below depicts a general overview of a typical irrigation scheme in Indonesia. An irrigation scheme in Indonesia can be divided into three different systems: (1) the main system, (2) the secondary system and (3) the tertiary system. Water is moved from a water source, which is most often a river, to the irrigation scheme through canals. The main system consists of one main channel that provides water for the whole irrigation scheme. Thereafter, water is transferred trough a smaller channel (secondary system) to the tertiary system, which exists of multiple farm blocks and has a service area of about 100 ha (Gany, 1993). Until the 1970s, farmers had total responsibility for the construction, operation and maintenance of the tertiary irrigation network and the main and secondary system were provided by governmental agencies. This was not successful, since farmers often did not have access to the required capital. The main idea behind the rehabilitation programs from 1969 onwards was therefore to improve irrigation on the tertiary level, and the government decided to help farmers with construction, operation and maintenance services for the tertiary level of the irrigation schemes (Gany, 1993). This was for example done by modernizing the channels on the farm block or by building water gates to control the water flow.

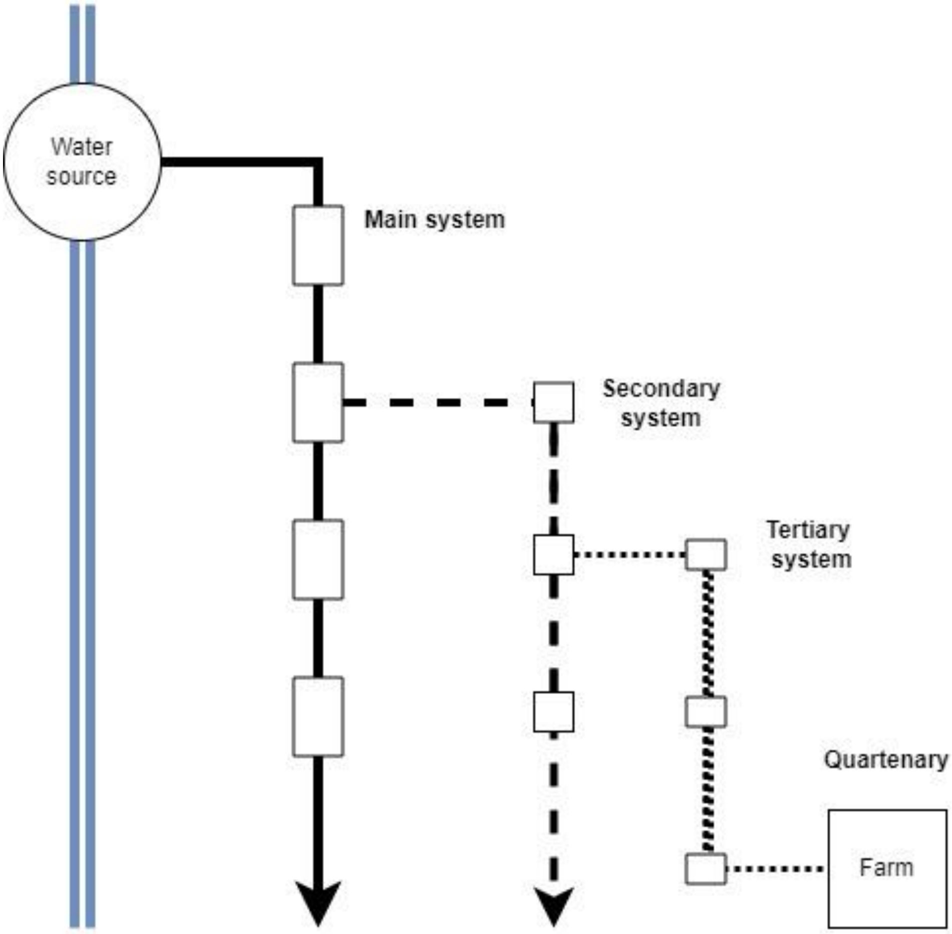


Figure 4: Simple overview of an Indonesian irrigation scheme. Source: Gany (1993)

Though irrigation systems clearly improved after the implementation of the Pelita's, irrigation systems in Indonesia still remained relatively limited. In general, irrigation can help with controlling the water supply during the growing season of the rice, and multiple studies have shown that irrigation improves paddy production (Grover & Upadhya, 2014; Kang et al., 2009; Stuecker et al., 2018; Yu & Fan, 2011). However, in Indonesia, most systems are 'run of the river' systems which only adequately operate during the occurrence of sufficient rainfall (Naylor et al., 2002). Contrary to Naylor et al. (2002), who claim that irrigation systems in Indonesia do not aid in decreasing the impact of delayed rainfall on agricultural production, a more recent study by Panuju et al. (2013) shows that irrigation systems helped to safeguard rice production in Indonesia between 1961 and 2009. This is because irrigation systems ensure that water is still provided to the paddy fields on days without rain. However, during longer periods of drought, or a delay of the beginning of the wet season, the water source will dry up. Only a small number of irrigation schemes on Java exist with dams that retain sufficient water for release during longer periods of drought. The question therefore arises to what extent the irrigation schemes in Indonesia help with mitigating rainfall variations such as rainfall delays or longer periods of droughts. This is investigated in the remainder of the thesis.

4. Research Methodology

This chapter provides an overview of the research methodology. A panel data regression analysis is the main method of this thesis. Therefore, a general explanation of panel data models is provided along with a description of the regression models used for this research. However, at first, the collected data is described and explained, followed by an overview of the constructed variables and the descriptive statistics of these variables.

4.1 Data collection

To be able to answer the research questions, four different types of data are collected. These are 1) rainfall data, 2) rice production data, 3) irrigation data and, 4) population data.

4.1.1 Rainfall data

As described in earlier sections, the focus of this thesis regarding weather variables is on rainfall only. Precipitation data is obtained from a gridded precipitation dataset produced by the Climate Research Unit (CRU) at the University of East Anglia (Harris et al., 2020). Gridded precipitation data provides a balanced panel and is therefore best suited for economic studies compared to weather station data (Dell et al., 2014). The dataset by Harris et al. (2020) is widely used and has a spatial resolution of 0.5 times 0.5 degrees. It covers the time period 1901-2021 and consist of monthly precipitation data over all land domains of the world (Harris et al., 2020). The dataset is provided as multidimensional raster data, and monthly precipitation data for every Indonesian province for the period 1950-2000 is acquired from the dataset by using ArcGIS Pro. This data is stored in Excel in panel form with provinces as entity and year as time unit. This also holds for data on rice, irrigation, and population.

4.1.2 Rice data

Data on rice is derived from the Statistical yearbooks of Indonesia published by Bureau Pusat Statistik (BPS) and made public by SouthEast Asian DEvelopment in the Long Term (Sea-Delt). The obtained data on rice consists of 1) harvested area of rice in hectares and 2) production of rice in metric tonnes. Data on rice production on a provincial scale in Indonesia is available from 1968 onwards. The data is available on the website of Sea-Delt in pdf format, and data on rice for the period 1968-2000 was manually entered into Excel.

4.1.3 Irrigation data

Data on irrigation is limited and not readily available, due to the lack of online available Indonesian governmental sources with data on irrigation in Indonesia during the period 1968-2000 on a provincial scale. This is a common problem, also mentioned by Naylor et al. (2002). The Statistical Yearbooks of Indonesia used for the rice data do not contain any useful data on irrigation systems. A distinction between irrigated and non-irrigated paddy production in the yearbooks exists for a limited number of years. For the other years, BPS distinguishes between wetland and dryland paddy harvested. This data is not suitable for this thesis since wetland area harvested also includes non-irrigated wetlands. The Directorate General of Water Resources Research (DGWRD) of the Ministry of Public Works is the governmental institution that is in charge of the irrigation systems in Indonesia. However, they do not have any online data available on irrigation in the period 1968-2000, not on their website nor on their online archives.

Due to the lack of available irrigation data, this thesis uses data from the World Bank on irrigation projects for this thesis. The World Bank has played a significant role in irrigation development in Indonesia, and World Bank data on irrigation in Indonesia therefore covers the majority of these developments (Suhardiman & Mollinga, 2012). In the late 1960s, the World Bank started with PROSIDA (Irrigation Project from International Development Agency), which was the countries first irrigation development project (NEDECO, 1978). PROSIDA continued until 1989 with ongoing support from the World Bank (Suhardiman & Mollinga, 2012). Table 1 in Appendix I shows an overview of all the irrigation projects in Indonesia during the period 1968-1989 implemented in partnership with the World Bank. Since the studied time period of this thesis is 1968-2000, this does indicate that irrigation developments during the 1990s are not covered by this study. This is a limitation of this research which is further elaborated on in the discussion.

Reports on the projects are obtained from the World Bank and two types of reports are used: Staff Appraisal Reports and Implementation Completion and Results Reports. The Staff Appraisal Reports are established at the beginning of the report and contain information on estimated costs, estimated size, location, a clear description, and the required capital for the successful completion of the project. Implementation Completion and Results Reports are created after the completion of the project and do contain information on the actual costs and sizes of the projects, a description of the successes and failures of the projects and the capital used for the implementation of the project. Two types of data from the reports can be seen as relevant: projects costs and projects size. Every report includes a clear overview of the project costs. However, in some cases, reports only contain an overview of the overall costs of all the sub-projects within the main project. This indicated that a distinction between the costs of sub-projects is missing, and costs cannot be estimated on a provincial scale since sub-projects from the same main projects can be located in different provinces. An overview of the project size of every sub-project is included in every Implementation Completion and Results Reports and can therefore be estimated on a provincial scale. This makes that data on project size is more suitable for this research compared to data on project costs.

Two types of data are acquired from the reports: the size of the irrigation projects and the size of tertiary development projects, both in hectares per province over the years. Tertiary development projects are irrigation projects that aim to rehabilitate irrigation schemes from the irrigation projects. More specifically, in some cases mistakes have been made during the implementation of the irrigation projects, whereafter the World Bank and Indonesian Government decided to rehabilitate or improve the previous implemented irrigation projects. This tertiary development data is stored as a separate variable since these hectares are already covered by the project size data. The data for both types of irrigation is manually entered into Excel.

4.1.4 Population data

Population data for all Indonesian provinces is obtained from the same statistical yearbooks as the rice data. This data was only available for the years 1961, 1970, 1980, 1990 and 2000. Population numbers for the other years are estimated by interpolating between these years by using Stata. After this process, this data is stored into Excel.

4.2 Constructed variables

Multiple variables are constructed to analyse the impact of rainfall variation on the Indonesia rice production, and to what extend this is mitigated by the implementation of irrigation projects. Table 3 below shows all the variables constructed for this research. A more detailed explanation of the different variables is provided below Table 3.

Table 3: List of variables used in the regression analysis with description and the units.

	Variables	***Unit***	***Description***
Non-weather variables	prod_dw (dependent variable)	*tonne*	Production of dryland + wetland paddy
	harv_area_dw	*hectare*	Area harvested of dryland + wetland paddy
	pop	*person*	Population
	project_ha	*hectare*	Size of irrigation projects
	td_ha	*hectare*	Size of tertiary developments projects
Weather-Variables	totprec	*mm*	Total annual precipitation (Jan – Dec)
	tprecgrow	*mm*	Total annual precipitation (Oct – Sep)
	totprec_ws	*mm*	Total precipitation during the wet season (Oct-Apr)
	totprec_g	*mm*	Total precipitation during the growing season of paddy (Oct-Feb)
	totprec_h	*mm*	Total precipitation during the harvest period of paddy (Mar-Apr)
	Negshock_g	*0/1*	Dummy variable which is set equal to 1 if totprec_g is more than one standard deviation below the mean
	Negshock_ws	*0/1*	Dummy variable which is set equal to 1 if totprec_ws is more than one standard deviation below the mean
	Posshock_g	*0/1*	Dummy variable which is set equal to 1 if totprec_g is more than one standard deviation above the mean
	Posshock_ws	*0/1*	Dummy variable which is set equal to 1 if totprec_ws is more than one standard deviation above the mean

4.2.1 Non-weather variables

The production of paddy is the dependent variable of the production function used for the panel data model. Traditionally, the vector of explanatory variables in a production function includes land, labour, and capital inputs (Oury, 1965). The harvested area variable accounts for land and the population accounts for labour. Total population is chosen as the labour variable due to limited available data on people working in the agricultural sector. The exclusion of a capital variable is also result of limited available data.

The irrigation variables cover the irrigation projects and are set up differently compared to other variables. For all provinces, these two variables start with 0 ha since none of the irrigation projects were completed in the beginning. When a project is completed, the size of the irrigated area in hectares is added to the province in which the projects is located. The irrigation variables preserve this value until a new project is completed in this province, which is then added to the old value.

4.2.2 Weather variables

All weather variables are based on the literature reviewed in chapter 2. The first total annual precipitation variable is based on the model used by Dhamira & Irham (2021), who studied the impact of El Niño/La Niña on rice production in Indonesia. The second total annual precipitation variable follows the reasoning of considering the growing season of crops as an important time frame instead of the calendar year. Rice planting in Indonesia usually starts in October, and this month is therefore used as the starting month. Precipitation is then measured for the 12 months that follow. In the panel, total precipitation for the period 'October year t - September year $t + 1$' is attached to year $t + 1$ since this variable has only influence on the rice harvest in that year.

The total precipitation during the complete wet season, growing season and harvest period variables are based on the model by Auffhammer et al. (2012), which used these variables to investigate the impact of weather on rice production in India. Besides this, these variables also follow the reasoning of basing the time frame of rainfall variables on the growing seasons of crops. The chosen months for both variables only approximately cover the growing season and the harvest period, since crop-establishment and harvest date vary across provinces and years due to variation of weather patterns. This is similar to the research by Auffhammer et al. (2012). The total precipitation during growing season and wet season variables are, equivalent to the second total annual precipitation variable, attached to year $t + 1$ in the panel (taking October year t as the base year).

The last four variables are weather shock variables. Weather shock variables always consist of a deviation or multiple deviations from the average, and in this research the deviation is one standard deviation (Blanc & Shlenker, 2017). Such variables are commonly used in models that aim to estimate the impact of weather on agricultural output (Dell et al., 2014), and are therefore also included in the models in this thesis. These variables are dummy variables and, in this study, the variables are coded as a shock if the total rainfall during the given period is more than one standard deviation above or below the mean.

4.3 Descriptive statistics

In Table 4 below, the descriptive statistics of each variable from Table 3 are presented. This includes the number of observations, mean, standard deviation, minimum value, and maximum value. The total number of observations ($N = 825$) is based on observations for 25 provinces over 33 years (1968-2000). The original dataset included 26 provinces; however it is decided to exclude D.K.I. Jakarta from the dataset. This province is completely covered by the city of Jakarta, does not have any irrigated area and average annual rice harvest in this province is almost zero. This makes the province irrelevant for this research.

Table 4: Descriptive statistics of all the variables used in the regression models.

Variable	**Obs**	**Mean**	**Std. Dev.**	**Min**	**Max**
prod dw	825	1473696.8	2293219.6	698	10863393
harv area dw	825	387526.5	496351.94	519	2188479
pop	825	6116464.4	8967142.1	494190	43822000
project ha	825	33012.582	99924.837	0	499300
td ha	825	10716.056	47140.906	0	318195
totprec	825	2508.629	509.563	1043.321	3842.419
tprecgrow	825	2502.608	463.044	1369.3	3857.757
totprec ws	825	1762.749	346.03	692.964	2728.991
totprec g	825	1244.559	280.286	359.609	2053.437
totprec h	825	518.19	123.386	164.34	953
negshock g	825	.152	.359	0	1
negshock ws	825	.142	.349	0	1
posshock g	825	.141	.348	0	1
posshock ws	825	.143	.35	0	1

4.4 Panel data model

This section provides a brief explanation of the use of panel data models in general, followed by an explanation of why this method is relevant for this research. Thereafter, different models are described. The regression analyses of these models should make it possible to answer the second and third sub-question, as well as the main research question.

A panel data model is a common approach to estimate the impact of weather variables on rice yield (Pattanayak & Kumar, 2014). A panel data model is a regression model, which consists of observations of each entity repeated over a period of time within a spatial unit (e.g., counties, districts, countries) (Pattanayak & Kumar, 2014; Woolridge, 2015). Panel studies are able to exploit year-to-year changes of temperature, precipitation, and other climatic variables for the identification of a relationship between climate and agricultural output (Blanc & Schlenker, 2017; Dell et al., 2014). Panel data models are most useful for investigating the impact of climate on agricultural output since it, unlike other approaches (e.g., the cross-sectional approach), takes unobserved variables into account (Blanc & Schlenker, 2017). For a basic panel model, the output is a function of explanatory variables, fixed effects, and an error term (Blanc & Schlenker, 2017; Pattanayak & Kumar, 2014). The vector of the explanatory variables can include multiple different factors (e.g., land, labour, capital). However, since weather is a key determinant for agricultural production, weather variables (e.g., precipitation) are always included in panel models on agricultural output (Blanc & Schlenker, 2017). There are two types of fixed effects: fixed effects for spatial units and time fixed effects. Fixed effects for spatial units account for unobserved time-constant factors that vary across spatial units. Time fixed effects account for time-varying unobserved factors that affect all spatial units in the same way (Dell et al., 2014).

The aim of this research is to investigate the impact of weather variables on agricultural output, and as described above, a panel data model is a common approach to investigate this. More specifically, panel data models account for the fact that different locations (in this research provinces) do not only exhibit differences regarding weather variables, but also regarding many other variables with the inclusion of fixed effects (Blanc & Schlenker, 2017). Examples of such variables relevant to this research are soil quality, appliance of fertilizer or personal characteristic of farmers. The list of such variables is endless which makes it is impossible to obtain all the necessary data. By including fixed effects for spatial units in the final model, the omission of these variables does not bias the coefficients of the weather variables (Blanc & Schlenker, 2017; Dell et al., 2014). Additional to this, the inclusion of time fixed effects covers the impact of larger time-varying but location-constant effects (Blanc & Schlenker, 2017; Dell et al., 2014). For this research, this is for example the impact of the green revolution on the agricultural sector of Indonesia. The construction of the model used for the regression analysis of this research is explained in the following section. The model used is based on the literature review on the impact of weather variation on economic outputs by Dell et al. (2014), who provide a basic model based on many studies on this topic.

4.4.1 Regression models

In the regression models, the second and third sub-question and the main research question are addressed. The main goals are 1) to estimate the impact of different types of weather variation on the Indonesian rice output, 2) to estimate the impact of irrigation programs on the Indonesian rice output and finally 3) to estimate the extent to which irrigation infrastructure enhances resilience of rice cultivation in terms of weather variation in Indonesia. To be able to achieve these goals, four different models are constructed.

The first model (1) is a simple production function and is used as a sanity check. This model does not include any irrigation or weather variable. The function of this model is to investigate if the acquired data on rice and population is reliable, and it is specified as follows:

$$y_{it} = \beta_0 + \beta_1 P_{it} + \beta_2 A_{it} + \mu_i + \theta_t + \varepsilon_{it} \tag{1}$$

In this production function, y_{it} is production of rice in year t in province i; β_0 is the constant; P_{it} is population; A_{it} is harvested area; μ_i and θ_t are respectively the fixed effects for the provinces and the time fixed effects; and ε_{it} is the error term. Table 5 shows the regression results of this first model. As expected, both harvested area and population are found to have a highly significant impact on the rice production with a 99% confidence level and are therefore included in all models.

Table 5: Regression results model 1

	(1)
harv area dw	5.941***
pop	0.168***
Fixed effects	Yes
Year-fixed effects	Yes
N	825
R^2	0.912

Notes: The results were obtained estimating Equation (1) using prod dw as the dependent variable. Nonrobust standard errors are in parentheses below the estimated coefficients.
*** p<.01, ** p<.05, * p<.1

After the regression analysis of model 1, rainfall variables from Table 3 are included in the model. Only one rainfall variable is included each time to test which of the variables has a significant impact on the total rice production. The regression analysis of this model is used to answer the second sub-question of this thesis. Additionally, weather variable(s) that have a significant impact on rice production are included in model 3 and 4, in order to investigate if and how irrigation projects influence the impact of rainfall variation on rice harvest. By including the precipitation variable (Z_{it}), model 2 is specified as follows:

$$y_{it} = \beta_0 + \beta_1 P_{it} + \beta_2 A_{it} + \beta_3 Z_{it} + \mu_i + \theta_t + \varepsilon_{it} \qquad (2)$$

In model 3, the two irrigation variables are also included together with the precipitation variable(s). The regression model estimates a possible impact of irrigation programs on the rice production, and the results provides the base to answer the third sub-question of this research. The analysis of this model (3) only provides information about the general impact of the irrigation projects on rice harvest, without any relation to weather variation. In this model IP_{it} is the size of the irrigation projects in year t in province i, while TD_{it} is the size of the tertiary development projects. The model is specified as follows:

$$y_{it} = \beta_0 + \beta_1 P_{it} + \beta_2 A_{it} + \beta_3 Z_{it} + \beta_4 IP_{it} + \beta_5 TD_{it} + \mu_i + \theta_t + \varepsilon_{it} \qquad (3)$$

To be able to answer the main research question, it is needed to create a model with an interacting variable between one of the irrigation variables and the precipitation variable included. The coefficient of this variable provides information about the influence of irrigation projects on the impact of weather variation on the rice production. While there are two irrigation variables, the interacting variable is only created with the general irrigation project variable and not with the tertiary development variable. The main reasoning behind using only one interacting variable is that it makes it much easier to understand and interpret regression results, which should lead to a better answer to the main research question. The general irrigation project variable is chosen as the variable to interact with the weather variable because this variable covers much more of the irrigation projects compared to the tertiary development variable. By including the interacting variable, model 4 is specified as follows.

$$y_{it} = \beta_0 + \beta_1 P_{it} + \beta_2 A_{it} + \beta_3 Z_{it} + \beta_4 IP_{it} + \beta_5 TD_{it} + \beta_6 IP_{it} Z_{it} + \mu_i + \theta_t + \varepsilon_{it} \quad (4)$$

The results of the regression analyses are described in the results section. The interpretation of these results, which should lead to answers to the main research question and sub-questions, are included in the discussion.

5. Results

Table 6 below shows complete regression results. Every column shows the results of one of the regression models as described in the methodology. Because the dependent and independent variables are in levels, the parameter estimates of the models indicate the following: a one unit increase in an independent variable causes a mean increase or decrease of rice production in metric tonnes in a given province for a given year when keeping the levels of the other independent variables constant. It indicates an increase when the coefficient shows a positive value and a decrease when the coefficient shows a negative value.

Table 6: Parameter estimates on variables in regression models (2, 3 & 4)

	(2)	(3)	(4)
harv area dw	5.916***	5.675***	5.654***
	(0.174)	(0.148)	(0.148)
pop	0.168***	0.012	0.016
	(0.007)	(0.01)	(0.01)
negshock g	-46515.684*	-26281.829	-19270.399
	(25949.871)	(21479.361)	(21636.462)
project ha		2.078***	2.140***
		(0.188)	(0.189)
td ha		5.005***	4.810***
		(0.387)	(0.395)
negshock g x project ha			-0.501**
			(0.219)
Fixed effects	Yes	Yes	Yes
Year-fixed effects	Yes	Yes	Yes
N	825	825	825
R^2	0.913	0.940	0.941

Notes: The results were obtained estimating Equation (2), (3) ,and (4) using prod dw as the dependent variable. Nonrobust standard errors are in parentheses below the estimated coefficients.
*** p<.01, ** p<.05, * p<.1

For the first model (2), the impact of different types of weather variation on the Indonesia rice output is investigated. Only a negative rainfall shock during the growing season of rice appeared to have a significant negative impact on rice production. The other weather variables have not found to have a significant impact, and complete regression results of models with these other weather variables included can be found in Appendix II (Table 1). The negative rainfall shock variable is a dummy variable, which means that the result indicates that the occurrence of a negative rainfall shock causes an average decrease of 46515.68 tonnes of produced rice. Besides this, the inclusion of this variable did not cause any changes regarding the coefficient and the significance level of the harvested area and population variables. One additional hectare of harvested area causes a 5.92 tonnes increase of produced rice, while this is 0.17 tonnes for a population increase of one.

For the second regression (model 3), both irrigation variables are included together with negative weather shock variables. The inclusion of these variables produces some changes on the parameter estimates of the model compared to the regression results of model 2. Both irrigation variables have a highly significant, positive impact on rice production. One additional irrigated hectare (project ha) causes an increase of 2.01 tonnes of produced rice, while this is 5.01 tonnes for the tertiary development variable. The impact of harvested area on rice production remained its highly significant, similar positive impact on rice production. The impact of population on the rice production is less in model 3 compared to model 2, and also not significant. Similar to this, the negative impact of a negative rainfall shock on rice production is also less and not significant as a result of the inclusion of irrigation in the model (3).

The regression results of the final model (4) show a significant impact of the interaction between a negative weather shock and the presence of irrigation programs on the rice production. The coefficient of the interaction equals -0.501, which should be interpreted differently compared to the other variables since this is the result of an interaction between the continuous variable 'project ha' and the categorical variable 'negshock g'. 'Negshock g' is a dummy variable and is set equal to 1 during the occurrence of a negative rainfall shock. The variable is set equal to 0 during the absence of a negative rainfall shock. The interaction effect shows the estimated change of rice production during a rainfall shock for all provinces that are covered by World Bank projects. The coefficient of -0.501 therefore indicates that during a rainfall shock, one additional hectare of World Bank program coverage decreases the rice production by 0.501 tonnes. The coefficients of the other variables are similar to the results of model (3). The interpretation of the results of all models are discussed in following chapter, which also provides answers for the sub and main research question of this research.

6. Discussion

The objective of this research is to estimate the impact of weather variation on rice production in Indonesia, and to what extent this impact is mitigated by the implementation of irrigation programs. In this section, the results from the previous chapters are discussed in relation to this objective. Beside this, the implications of the results are discussed, the limitations of the study are mentioned, and suggestions and starting points for future research are provided.

6.1 Interpretation and implications of the results

From the regression analysis of model 2, it can be concluded that in general, rice production in Indonesia is not much affected by rainfall variation. The regression results of the model show that out of all tested rainfall variation variables, only the occurrence of a negative weather shock during the growing season of rice appeared to have a significant impact on the Indonesian rice production. This impact is negative, and since this variable is a dummy variable, the coefficient of this variable (-46515.684) can be interpreted as follows: during a negative weather shock, the average production per province of rice decreased by 46515.68 tonnes. For a better understanding of this result, a new variable is created which represents the difference of rice production per province between years in levels. Table 7 below depicts the descriptives statistics of this variable, and the average change in rice production is 38123.62 tonnes. So, while on average rice production increases with 38123.62 tonnes, rice production decreases with 46515.68 tonnes during the occurrence of a weather shock. This does show that a negative weather shock has a clear impact on rice output in Indonesia. However, it is hard to say something about the extent of this impact since these numbers are only based on averages. The impact of a shock is completely different between provinces and years, which can also be inferred from the high value of the Standard Deviation (Table 7).

Table 7: Descriptive statistics of the annual production change variable

Variable	Obs	Mean	Std. Dev.	Min	Max
Annual production change	800	38123.622	190845.77	-1569810	1574231

The reason that this variable is the only significant variable can be explained by the fact that the variable is most in line with the literature. As mentioned in the discussed literature in chapter 2, rice is mostly dependent on the starting date of the wet season (Naylor et al., 2002, 2007; Skoufias et al., 2012). A delay in the start of the wet-season, which also causes a delay in the growing season, has a negative impact on the rice production, and this delay is in some way covered by this variable. When the wet season starts later than normal, for example in December instead of October, the precipitation during the first 2 months of the growing season is lower. As a consequence, the amount of total precipitation during the 'normal growing' season of rice is lower, which can result into a much higher chance of a dummy-value of 1 as regards to this weather shock variable. That this is genuinely the case in this research can be supported by the following: the occurrence of an El Niño event delays the start of the wet-season (Naylor et al., 2001, 2002, 2007), which means that a negative weather shock during the growing season would occur much more often in El Niño years. As discussed in the literature, Ismail and Chan (2020) and Surmaini et al. (2015) estimated that the occurrence of a 'strong' or 'very strong' El Niño event has a significant negative impact on rice production due to less rainfall during the growing season. Table 8 below depicts the number of provinces that are impacted by a weather shock (negshock g) and the El Niño events for all years. As shown by this table, years when a 'strong' or 'very strong' event happened are also the years where most provinces are affected by a negative weather shock during the growing season. This shows that the negative, significant impact of this weather shock variable on rice production are very well in line with previous research.

Table 8: Weather shocks per provinces for all years. The values in the second column denote the number of provinces impacted by a negative weather shock during the growing season. The El Niño strengths are based on Table 3.

Year	***Number of provinces impacted by a negative weather shock.***	***El Niño (strength)***
1968	4	-
1969	5	Weak
1970	5	Weak
1971	0	-
1972	0	-
1973	18	Strong
1974	4	-
1975	1	-
1976	6	-
1977	2	Weak
1978	7	Weak
1979	2	-
1980	2	Weak
1981	3	-
1982	2	-
1983	19	Very Strong
1984	0	-
1985	2	-
1986	0	-
1987	3	Moderate
1988	3	Moderate
1989	2	-
1990	0	-
1991	2	-
1992	6	Moderate
1993	3	-
1994	1	-
1995	1	-
1996	0	-
1997	1	-
1998	21	Very Strong
1999	0	-
2000	0	-

The results of model 3 show that irrigation programs have a, positive, significant impact on rice production in Indonesia. The coefficients in Table 6 (model 3) indicate that one additional irrigation project hectare causes an average increase of 2.01 tonnes of produced rice, while one additional tertiary development project hectare causes an average increase of 5.01 tonnes. From this can be concluded that the irrigation programs from the World Bank and the Indonesian government have a clear positive impact on the rice output between 1968-2000. This conclusion is expected, based on the study by Panuju et al. (2013) who estimated that irrigation systems help with ensuring rice production Indonesia in a similar period. Also, Pasandaran & Zuliasri (2001) concluded that implementation of the irrigation programs was one of the main reasons behind Indonesia's achievement of becoming rice self-sufficient in 1984. Besides this, the better performance of the tertiary development projects compared to the normal irrigation projects is also expected. As explained in the description of the irrigation data, tertiary development projects are projects that furtherly improved the irrigation systems from the normal irrigation projects if this was needed. So, the tertiary development projects existed of only furtherly improved irrigation systems, while this is not the case for the normal irrigation projects, and it is therefore logical that these improved irrigation systems have a larger, positive impact to on the rice production.

From the regression analysis of the final model, it is possible to conclude that irrigation programs do not enhance the climate resilience of rice production in Indonesia in the period 1968-2000 in terms of weather variation. This conclusion is in line with the previous mentioned study by Naylor et al. (2002) who claim that irrigation systems do not aid in decreasing the impact of delayed rainfall on agricultural production. The results show that one additional irrigation project hectare causes an average decrease of 0.501 tonnes of produced rice if a negative weather shock during the growing season occurs. This shows that irrigation programs do not enhance resilience of rice cultivation in terms of weather variation, since a larger coverage of irrigation programs by the World Bank causes a further decrease in rice production during the occurrence of a negative rainfall shock. In conclusion, provinces with more irrigation programs coverage performed worse during rainfall shocks in terms of rice production, and irrigation programs have therefore not helped with mitigating the impact of rainfall shocks.

The results have several implications. Most importantly, this thesis builds onto existing literature that uses panel data to investigate the impact of climatic factors on agricultural production which is essential for the effective design of future policies and institutions (Dell et al., 2014). Besides this, this thesis contributes to literature on enhancing irrigated agriculture, which is, as mentioned by Ward (2022) and as shown by the regression results of model 2, of high importance due to the negative impact of rainfall variation on agricultural output which can be mitigated by irrigation. Also important to mention is that different types of weather variation will occur more often as a consequence of climate change, and effective irrigation systems are therefore highly needed (Ward, 2022). Since this thesis has shown that the Indonesian irrigation programs conducted by the World Banke have improved the rice production in Indonesia in general, policymakers can use the information provided by the results and by the overview on irrigation development in chapter 3 for the design of future polices to ensure effective irrigation systems. However, the results also showed that the irrigation programs have not enhanced resilience of rice cultivation in terms of weather variation, which is important for the policymakers to take into account when using the information provided in this research.

6.2 Limitations and recommendations for future research

This study has multiple limitations that should be addressed. At first, this study uses a gridded precipitation dataset which has some limitations as mentioned by Dell et al. (2014). Gridded datasets interpolate among different ground stations to estimate the precipitation per grid. However, interpolation can produce different estimates compared to the actual precipitation due to two reasons. Firstly, precipitation shows great spatial variation, especially in rugged areas, which makes it much more difficult to interpolate. Secondly, and this is most relevant to middle- and low-income countries, an issue occurs if there are more grid cells than ground stations. Both issues are relevant to Indonesia, especially to the outer islands, and it is therefore important to be aware of the fact that the precipitation values used for this research can be different compared to the actual precipitation values. As regards to the second issue, there has been dealt with this to some extent by using a dataset with a spatial resolution of 0.5 x 0.5 degrees, instead of a dataset with a spatial resolution of 0.25 x 0.25 degrees.

Secondly, it is important to be critical on the reliability of the data derived from the BPS yearbooks. According to van der Eng (2022), the BPS does not provide any information about the used methodology for the data collection after the 1960s. The reason behind this is unclear, but this does mean that it is difficult to assess the quality of the data, and this is important to bear in mind. Another limitation as regards to the data is the lack of available data on irrigation. This has already briefly been mentioned earlier in this thesis but is important to highlight again since a more extensive irrigation dataset could have led to different results. For example, irrigation developments on Bali are not included in this research since the irrigation projects from the rehabilitation programs were not located on Bali due to the different irrigation management approach of the local government. However, irrigation facilities have been widely rehabilitated and constructed on Bali during the 1970s and 1980s (Lorenzen & Lorenzen, 2008). Specific data on this is not available, and therefore not included in this study. However, Bali had one of the highest yields of Indonesia during the period 1968-200, and the inclusion of these irrigation projects in this study could therefore have a significant impact on the results.

One limitation as regards to the variables of the regression models is that these are in levels instead of logs. The irrigation data include many values that denote 0, which would have caused problems if the variables were in logarithmic form. However, a logarithmic form allows variables to equal elasticities, which makes it easier to interpret the relationship between the independent variables and the dependent variable and could provide better results. Another limitation related to the variables is the problem of endogeneity. The dependent variable of the regression models in this thesis is rice harvest instead of yield to avoid the inclusion of a ratio variable in a linear regression which could lead to a misspecification of the model (Lien et al., 2017). However, the inclusion of both a rice output and harvested area variable could lead to the statistical problem of endogeneity caused by the simultaneous determination of the harvested area with the quantity of the rice output (Auffhammer et., 2012). A last limitation of this research is that this research only looks to the whole of Indonesia, and does not use any samples to investigate any differences between

Resulting from these limitations, suggestions for future research to use and further develop the panel models to estimate better and more precise results, as well as to get a better understanding of these results are as follows. At first, they could split the different provinces into two different samples to investigate differences of this impact between high- and low-producing provinces. Because the impact for the high-producing provinces is of much more importance for the Indonesian economy compared to that of the low-producing provinces.

At second, it is suggested for future research on this topic to use variables in logarithmic form for the regression models. In the previous paragraph, there is already discussed why this is important, but it is important to also mention it in this section since it would give a much better idea about the extent of the impact of irrigation systems relating to enhancing resilience of rice cultivation in Indonesia in the period 1968-2000 in terms of rainfall variation. From the results of this research, it has become clear that irrigation programs do not mitigate the impact of weather variation on rice production, however the actual size of this impact is still unknown.

The last suggestion is to also include temperature variables. While Indonesia does not show much variation in temperature (Levine & Yang, 2014), studies have already shown that the impact of higher temperatures on rice output is highly significant and often negative (Auffhammer et al., 2012; Peng et al. 2004; Seshu & Cady 1984; Wassmann et al. 2009; Yoshida & Parao 1976). Besides this, studies have estimated that irrigation can decrease temperature on a local scale and can therefore help with mitigating the impact of increasing temperatures (Chen & Dirmeyer, 2019; Kueppers et al., 2007; Lobell et al., 2008; Thiery et al., 2017). Applying this to this research therefore expands the knowledge in terms of what different types of weather variation impact the Indonesia rice production, and how this impact can be mitigated by irrigation infrastructure.

7. Conclusion

Global food demand is increasing with a rapid pace. Simultaneously, climate change is putting a growing amount of pressure on global food production. Measures that decrease this pressure are therefore required, and irrigation is seen as one of these measures. However, to what extent irrigation infrastructure helps with this differs much, and research on this topic is therefore required. To be able to contribute by answering the following research question: *To what extent have irrigation programs enhanced resilience of rice cultivation in terms of weather variation in Indonesia between 1968-2000?*

From the literature review on the impact of weather on the Indonesian rice cultivation became clear that the amount of rainfall during the growing season of rice and the start of the wet season have the most impact on rice cultivation in Indonesia in terms of climatic factors. The literature review on irrigation in Indonesia showed that the government, in collaboration with the World Bank, heavily invested in the development of the Indonesian irrigation infrastructure by designing and implementing several irrigation programs. While this has enormously contributed to the increasing rice production between 1968 and 2000, irrigation systems did not always succeed, and the design of the irrigation schemes were still relatively simple.

The regression analyses from the panel models showed that a negative rainfall shock during the growing season of rice, which was also the only significant weather variation variable, caused an average decrease of 46515.68 tonnes of rice. From this result can be concluded that in general, rice cultivation is not that much influenced by rainfall as expected. It became also clear from regression results that every additional hectare of irrigation project increases the average production by 2.01 tonnes, while this is 5.01 tonnes for the tertiary development projects. This indicates that the general impact of irrigation programs on rice cultivation in Indonesia is positive. The final regression analysis showed that during a negative rainfall shock, provinces with a higher coverage of World Bank projects produce less rice. More specifically, during negative rainfall shock, one additional hectare of World Bank coverage decreases the rice production by 0.501 tonnes.

This indicates that, when looking at the research question, irrigation programs have not enhanced climate resilience of rice cultivation in terms of weather variation in Indonesia between 1968-2000. This contributes to a better understanding on enhancing climate resilience of irrigated agriculture, since the results indicate that the Indonesia irrigation systems do help with mitigating the impact of rainfall shocks and this information can be used for the design of future polices relating to the effective implementation of irrigation systems.

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Appendix I

Table 1: Overview of irrigation projects in Indonesia funded by the World Bank during the period 1969-1989.

Projects	Island(s)	Province(s)	Project description	Years
Irrigation project 1	*Java and Sumatera*	West Java Central Java Lampung	Rehabilitation of existing irrigation systems on Java and the construction of new irrigation schemes on Sumatera	1969 - 1976
Irrigation project 2	*Java*	West Java	Rehabilitation of existing irrigation systems on Java	1970 - 1979
Irrigation project 3	*Java and Sumatera*	West Java Central Java Lampung	Rehabilitation of existing irrigation systems on Java and South Sulawesi	1970 – 1979
Irrigation project 4	*Java*	East Java	Rehabilitation and improvement of existing irrigation systems on Java	1972 - 1979
Jatiluhur Irrigation	*Java*	West Java	Improvement and expansion of agricultural	1974 - 1982

Extension Project			services and irrigation	
Irrigation project 6	*Java*	West Java East Java	Rehabilitation and improvement of existing irrigation systems in West Java and the construction of new irrigation systems in East Java	1975 - 1984
Irrigation project 7	*Java and Sumatera*	West Java Central Java East Java Lampung	Improvement of existing irrigation systems on Java and Sumatera, tertiary development on Java and Sumatera and the construction of new systems on Sumatera	1976-1983
Irrigation project 8	*Java*	West Java East Java	Rehabilitation of existing irrigation systems on Java	1977-1985
Irrigation project 9	*Java and Sumatera*	Central Java West Sumatera	Rehabilitation and improvement of existing irrigation	1977-1984

			systems in Central Java and the construction of new irrigation schemes in West Sumatera	
Irrigation project 10	*Java and Sumatera*	Yogyakarta Lampung	Rehabilitation and improvement of existing irrigation systems in Yogyakarta and Lampung and the construction of new irrigation schemes in Lampung	1978-1986
Irrigation project 11	*Java*	West Java	Construction of a new irrigation system	1978-1984
Irrigation project 12	*Java*	West Java	Tertiary development on 186,000 ha of land in West Java and the rehabilitation and improvement of existing irrigation systems (5,000 ha) in West Java	1978-1986
Lower Cimanuk	*Java*	West Java	Construction and	1979-1985

Basin Flood Control Project			rehabilitation of flood protection works in West Java to protect 90,000 ha of irrigated area	
Irrigation project 14	*Java*	Central Java East Java	Flood protection, rehabilitation of existing irrigation systems in Central Java and the construction of irrigation systems in Central Java and East Java	1980-1987
Irrigation project 15	*Sulawesi and Sumatera*	North Sulawesi West Sumatera	Construction of new irrigation systems in North Sulawesi and improvement of irrigation systems in West Sumatera	1980-1987
Irrigation project 16	*Sumatera*	West Sumatera	Development of irrigation systems in West Sumatera	1982-1988
Irrigation project 17	*Java*	East Java	Rehabilitation, development and upgrading of existing irrigation systems	1982-1989

Provincial Irrigation Development Project	*Sulawesi and Sumatera*	North Sulawesi, Central Sulawesi, South Sulawesi, Southeast Sulawesi, South Sumatera, Riau, West Sumatera, Bengkulu	Construction of new irrigation schemes on Sulawesi and Sumatera	1984-1988

Appendix II

Table 1: Complete regression results of all insignificant weather variation variables.

Regression results

prod_dw	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
harv_area_dw	5.952	.174	34.19	0	5.61	6.294	***
pop	.168	.007	24.42	0	.154	.181	***
totprec	-29.969	31.49	-0.95	.342	-91.787	31.848	
Constant	-1703046.6	105445.87	-16.15	0	-1910044.2	-1496049	***

Mean dependent var	1473696.770	SD dependent var	2293219.556
R-squared	0.912	Number of obs	825
F-test	227.502	Prob > F	0.000
Akaike crit. (AIC)	22596.468	Bayesian crit. (BIC)	22766.222

*** *p<.01, ** p<.05, * p<.1*

Regression results

prod_dw	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
harv_area_dw	5.95	.174	34.22	0	5.609	6.291	***
pop	.168	.007	24.45	0	.154	.181	***
tprecgrow	-39.295	34.642	-1.13	.257	-107.299	28.709	
Constant	-1681562	109581.19	-15.35	0	-1896677.6	-1466446.5	***

Mean dependent var	1473696.770	SD dependent var	2293219.556
R-squared	0.912	Number of obs	825
F-test	227.626	Prob > F	0.000
Akaike crit. (AIC)	22596.058	Bayesian crit. (BIC)	22765.811

*** *p<.01, ** p<.05, * p<.1*

Regression results

prod_dw	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
harv_area_dw	5.944	.174	34.24	0	5.603	6.285	***
pop	.168	.007	24.38	0	.154	.181	***
totprec_ws	65.981	46.524	1.42	.157	-25.348	157.311	
Constant	-1894634.1	97682.735	-19.40	0	-2086392.2	-1702876.1	***

Mean dependent var	1473696.770	SD dependent var	2293219.556
R-squared	0.912	Number of obs	825
F-test	227.862	Prob > F	0.000
Akaike crit. (AIC)	22595.278	Bayesian crit. (BIC)	22765.032

**** p<.01, ** p<.05, * p<.1*

Regression results

prod_dw	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
harv_area_dw	5.94	.173	34.24	0	5.6	6.281	***
pop	.167	.007	24.38	0	.154	.181	***
totprec_g	93.109	52.588	1.77	.077	-10.125	196.343	*
Constant	-1889974.1	84232.482	-22.44	0	-2055328.4	-1724619.9	***

Mean dependent var	1473696.770	SD dependent var	2293219.556
R-squared	0.913	Number of obs	825
F-test	228.228	Prob > F	0.000
Akaike crit. (AIC)	22594.070	Bayesian crit. (BIC)	22763.824

**** p<.01, ** p<.05, * p<.1*

Regression results

prod_dw	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
harv_area_dw	5.94	.174	34.16	0	5.598	6.281	***
pop	.168	.007	24.46	0	.155	.182	***
totprec_h	-29.067	96.409	-0.30	.763	-218.325	160.191	
Constant	-1769987.8	79100.401	-22.38	0	-1925267.4	-1614708.2	***

Mean dependent var	1473696.770	SD dependent var	2293219.556
R-squared	0.912	Number of obs	825
F-test	227.237	Prob > F	0.000
Akaike crit. (AIC)	22597.346	Bayesian crit. (BIC)	22767.100

**** p<.01, ** p<.05, * p<.1*

Regression results

prod_dw	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
harv_area_dw	5.916	.174	33.99	0	5.574	6.257	***
pop	.168	.007	24.55	0	.155	.182	***
negshock_g	-46515.684	25949.871	-1.79	.073	-97457.094	4425.725	*
Constant	-1771234.5	60604.858	-29.23	0	-1890206.1	-1652262.9	***

Mean dependent var	1473696.770	SD dependent var	2293219.556
R-squared	0.913	Number of obs	825
F-test	228.253	Prob > F	0.000
Akaike crit. (AIC)	22593.986	Bayesian crit. (BIC)	22763.740

**** p<.01, ** p<.05, * p<.1*

Regression results

prod_dw	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
harv_area_dw	5.94	.174	34.17	0	5.599	6.282	***
pop	.168	.007	24.46	0	.155	.182	***
negshock_ws	-5931.635	25836.978	-0.23	.818	-56651.427	44788.158	
Constant	-1785053.3	60232.817	-29.64	0	-1903294.6	-1666812.1	***

Mean dependent var	1473696.770	SD dependent var	2293219.556
R-squared	0.912	Number of obs	825
F-test	227.224	Prob > F	0.000
Akaike crit. (AIC)	22597.387	Bayesian crit. (BIC)	22767.141

**** p<.01, ** p<.05, * p<.1*

Regression results

prod_dw	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
harv_area_dw	5.946	.174	34.19	0	5.604	6.287	***
pop	.168	.007	24.30	0	.154	.181	***
posshock_ws	16470.744	23817.206	0.69	.489	-30284.095	63225.583	
Constant	-1785706.5	60191.636	-29.67	0	-1903866.9	-1667546.1	***

Mean dependent var	1473696.770	SD dependent var	2293219.556
R-squared	0.912	Number of obs	825
F-test	227.363	Prob > F	0.000
Akaike crit. (AIC)	22596.928	Bayesian crit. (BIC)	22766.682

**** p<.01, ** p<.05, * p<.1*