Does climate change cause conflict? Damned if you do, damned if you don't

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Abstract:

Using detailed data on conflict-related incidents in Indonesia, we exploit seasonal variation in the relationship between rainfall and agricultural production to study the mechanism linking climate change and conflict. Furthermore, we ask whether irrigation and dam infrastructure help mitigate this link. We find that wet-season rainfall decreases production while rainfall during the dry season is beneficial for production. If agriculture is the mechanism through which climate change affects conflict, then we should expect the opposite effect on conflict, but with one-year lag. Our results show that, as expected, dry-season rainfall decreases conflict in Indonesia and in agricultural regions like Java, while wet-season rainfall increases conflict. In the latter, we find that irrigation increases conflict instead of reducing it. For Indonesia, irrigation reduces the effect of conflict during the dry season and amplifies it during the wet season. A plausible explanation is that the irrigation network is not well adapted to agriculture necessities which could generate civil unrest when a weather shock occurs. A policy that aim to reducing the impact of climate change on civil conflict should consider these drawbacks.

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I. Introduction

National security, global instability and human welfare are threatened by climate change. While growing evidence indicates that rising temperatures and changing rainfall patterns are likely to increase civil conflict and geopolitical instability, little is known about the underlying mechanisms through which climate change affects conflict. A number of papers find that climate shocks can increase conflict, largely in Sub-Saharan Africa. These authors suggest that the effect flows through agricultural production (Hsiang & Burke, 2014; Sarsons, 2015; Miguel & Satyanath, 2011; Miguel, Satyanath, & Sergenti, 2004), but for the most part are constrained to use coarse measures of climate shocks such as national, annual rainfall, which may or may not be relevant for agricultural production. Little work explicitly tests if and how agricultural production shocks are the key mechanism for these findings (recent work by Crost et al. (2015) is an exception). An understanding of these mechanisms is needed for policy-makers to develop interventions that build social and economic resilience to climate change. In this paper, we follow Crost et al. (2015) and Sarsons (2015) to explore whether agriculturally-relevant climate shocks affect conflict in Indonesia, and further, we ask whether irrigation and dams infrastructure helps mitigate this link.

The literature of rainfall and conflict outside Africa is limited. In the Philippines, Crost et al. (2015) use data on rice growing seasons and areas to find that agriculture is a potentially important causal link between shocks like drought or excessive rainfall and conflict escalation. Excess rainfall during the wet season negatively affects rice production and increases conflict and casualties the following year, while rainfall during the dry season increases rice production and reduces conflict. Likewise, Caruso, Petrarca, and Ricciuti (2016) find a linkage between temperature and violence in Indonesia. Their results show that an increase in the minimum temperature during the rice growing season leads to an increase in violence.

However, both studies use data at a high spatial and temporal aggregation, which limits the ability to disentangle the agricultural mechanism. The production data are usually obtained at province by year, which limits the ability to control for seasonality and regional variation. One exception is Sarsons (2015) who explores the impact of climate change on conflict in India using district-level data. She separates rain-fed and dam-fed agricultural regions, noting that we would expect to find that rainfall has a strong effect on conflict in rain-fed areas. She finds that there is a link between rainfall and conflict through the agriculture mechanism in India. Because of the disaggregated data, she found an unexpected effect on downstream agricultural areas. While these areas would be expected to be less dependent on rainfall because of the existence of irrigation, her results show the opposite. Downstream areas are more sensitive to rainfall shocks compared to upstream areas.

Indonesia, because of its location and geography, is exposed to significant variation in seasonal rainfall. For instance, Indonesia rainfall range in a year goes from 1,000 to 5,000 millimeters (Global Rice Science Partnership (GRiSP), 2013). Consequently, islands that are next to each other have different main planting seasons: Java from October to March, Sumatra from July to September, and Sulawesi from May to June (*op cit.*). Agriculture production in Indonesia has several production seasons within a calendar year. Specifically, it has three rice seasons: a single wet season crop followed by two dry season crops. Above-average rainfall during the wet season (January through April) is harmful to agricultural production, while above-average rainfall during the dry season (May-December) is beneficial (USDA-FAS, 2016). In contrast, the Philippines has the dry season from January to April, and the wet season goes from May to

December. Hence, rainfall from January to April is beneficial and precipitations during the rest of the year may harm production.

The Indonesian government has invested in the country's irrigation system (Panuju, Mizuno, & Trisasongko, 2013). The first investments were made by the Dutch government prior to World War II and they occurred in the primary agricultural regions, which, correspondingly tended to be wealthier (i.e. Java and Sumatra islands have been developed first) (Kroef, 1963). Since then, the Indonesian government has built dams all around the country. It is possible to find dams even in Sulawesi, Kalimantan or Nusa Tenggara which are not the main production areas, provoking an expansion of the agricultural areas (Panuju et al., 2013).However, while the irrigation system expanded, some areas also stopped producing due to changes in land use and the inability of the irrigation system to adapt to changing agricultural needs rapidly (*op cit.*). While the system may have some rigidities, overall, we should expect the supply of irrigated water may reduce the impact of rainfall on agricultural production, thereby reducing conflict.

Using novel data on civil conflict in Indonesia for the period 1997-2014, we exploit seasonal and detailed spatial variation in the effect of rainfall on agricultural production, and infrastructure data on dams to gain a better understanding of the mechanisms through which rainfall affects conflict. We hypothesize that, if agricultural production is the mechanism through which rainfall affects civil conflict, then the relationship between rainfall and civil conflict should also exhibit seasonality but in the opposite direction and with a one-year lag. Moreover, we would expect that the presence of dams may weaken the effect of rainfall on conflict.

Our paper has three main contributions. First, we use data on rice production at district level to confirm that the effect of rainfall on rice production exhibits the expected seasonality. We show that above-average rainfall in the wet season of the previous year is associated with more conflict, while above-average rainfall in the dry season of the previous year is associated with less conflict. Second, we provide evidence that the effect of rainfall on conflict differs when considering the presence of irrigation which has implications for the design of policies that aim to mitigate the impact of climate change on civil conflict. Third, we provide new evidence about a Southeast country of Asia that has a rich, but unfortunate history of conflict.

II. Background

II.I. Climate change and conflict

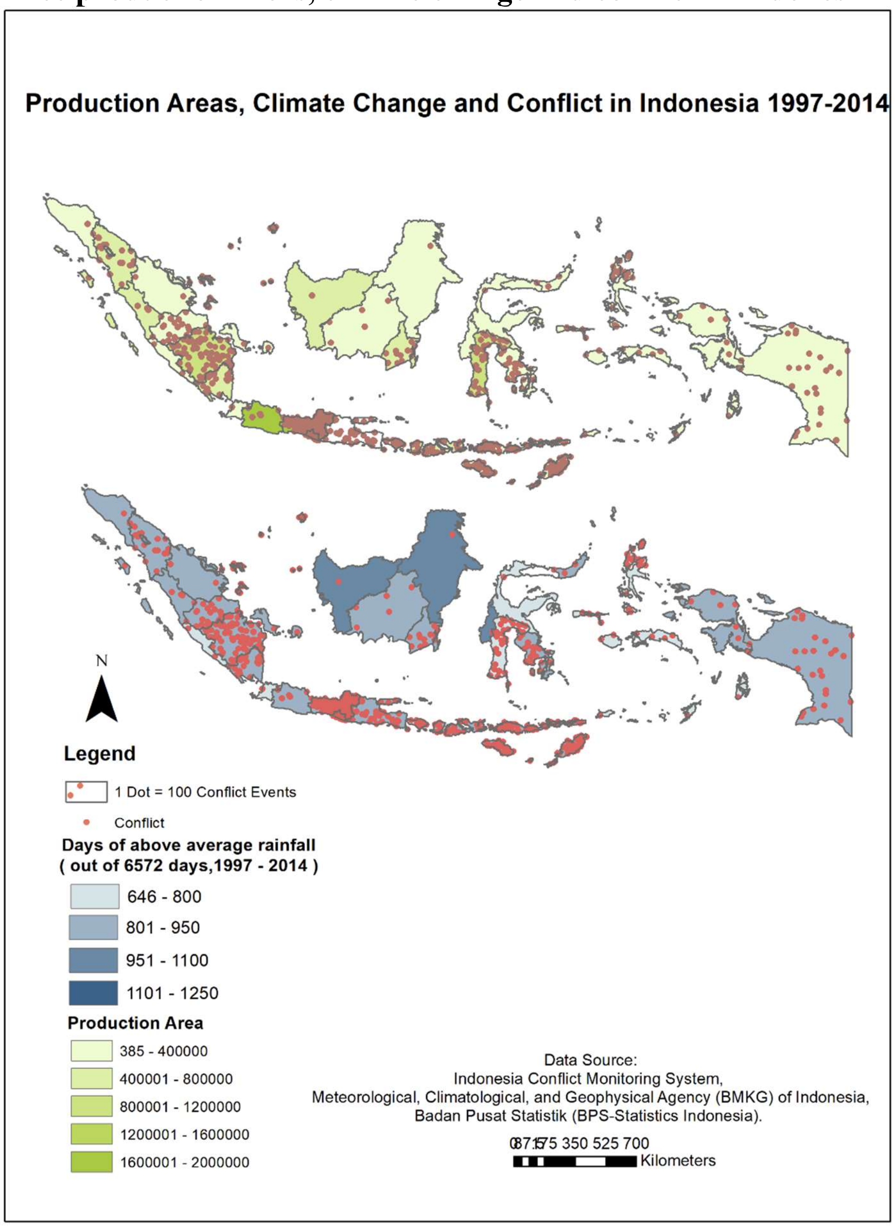
The studies about the link between climate change and conflict in Asia are limited. One of them is the work by Fetzer (2014) who finds a connection between monsoon rainfall and conflict in India. One of his main contributions is that public interventions such as rural income schemes may help to weaken the relationship between production shocks and civil unrest. Wischnath and Buhaug (2014) find a weak link between climate change and civil war in Asia. The results show that there is no systematic evidence on the relationship while one of the main challenges that arise is to look for alternative ways of modeling climate change and conflict. In the Philippines, Crost et al. (2015) find that excess rainfall during the wet season negatively affects rice production and increases conflict and casualties the following year, while rainfall during the dry season increases rice production and reduces conflict.

While the literature finds a relationship between climate shocks and migration or income (Kleemans, 2015; Kleemans & Magruder, 2016), there is less evidence on agriculture as the mechanism linking climate change and conflict. If agriculture is such mechanism then we should expect to see, for instance, that a negative shock destroying the harvest may increase conflict. However, this link might be stronger if the agriculture is an important part of the economy of the region in question. In our context, agriculture is an important sector of the Indonesian economy, representing approximately 14% of 2016 GDP (World Bank, 2017). Figure 1 also shows that the areas where rice production is important, rainfall have been above the mean for 800 to 950 days during the period 1997 to 2014. Moreover, areas where agriculture is important overlap the occurrence of conflict incidents.

However, irrigation is increasing agriculture's resilience to climate shocks. Indonesia has invested in developing irrigation networks since the country was a Dutch colony (Kroef, 1963). If the irrigation network works, then we should expect a decrease in the agriculture's dependence on rainfall shocks. Sarsons (2015) studied the relationship between rainfall and riots by separating upland and downland agriculture in India. She finds that downland areas were not independent from weather shocks, even when dams provide access to irrigation. Along the same line, Panuju et al., (2013) question the effectiveness of the irrigation network in Indonesia. These authors study the correlation between rice area, production and yield with irrigation. While they find a strong correlation (of close to 1) between these variables, there is a significant drop in the percentage of irrigated harvested rice area during the period from 1961 to 2009. Plausible explanations include the inability to maintain the irrigation network, limited irrigation network extension, abandoned areas that were previously developed, among others.

Even though water is not scarce through Indonesia, its distribution may also generate conflict in agriculture production. Failures in the provision of water when negative shocks occur, may generate civil unrest. For instance, Strau (2011) studies water management conflicts between wet land rice production and tourism activity in Bali. The lack of coordination between water use and economic priorities leads to water supply shortages in dry season for rice producers. On the other hand, public distribution might not be able to adapt to short-run climate shocks. In Indonesia, the Constitution (1945) and the Water Resources Development Act (1974) established that water use rights are assigned by the government. While the government retained the power of water distribution for the following 40 years, the New Water Law of 2004 states that the central government must respect individual basic needs and traditional irrigation rights when there is no conflict of interests.

Figure 1. Rice production areas, climate change and conflict in Indonesia 1997-2014



II.II. Agriculture and Rainfall

The main rice growing areas are on the islands of Java, Sumatra, Sulawesi, and Kalimantan. These islands produce more than 90% of the total rice production in 2015 (Figure 1). The island of Java is located at the south of Indonesia. The provinces of Jawa Barat, Jawa Tengah and Jawa Timur on Java host the main rice area and production. These three provinces account for more than 35 million tons of rice (47% national total production) and 5.8 million hectares (42% of national total area) (BPS-Statistics Indonesia, 2017).

There are typically three rice seasons in Indonesia: a single wet season crop followed by two dry season crops (USDA-FAS, 2016). Above-average rainfall during the wet season (January through April) is harmful to agricultural production, while above-average rainfall during the dry season (May-December) is beneficial. Both rainfed and irrigated crops are grown in the wet season, with rainfed crops accounting for approximately 15 percent of total area and 12 percent of total production. Wet-season rainfed rice is cultivated on an average of 1.0 million hectares and yields roughly 2.0 million metric tons of production (milled basis). Irrigation in upland reservoirs allow Indonesia to cultivate two additional rice crops during the long dry season when precipitation is typically too low to grow rainfed rice (*op. cit.*). By 2011, more than 50 percent of total rice area is routinely cultivated during the dry season (2nd and 3rd crops), which was impossible before developing the national irrigation system (USDA-FAS, 2012).

II.III. Civil Conflict in Indonesia

Since its declaration of independence in 1949, Indonesia has suffered a number of internal conflicts, often in the form of regional disputes with the central government. Many of these are related to resource scarcity, and disputes over productive land (Barber, 1998; de Vos, 2016; Strau, 2011). Historically, the main natural resource of Indonesia is its forest (Barber, 1998). Since

Suharto came into power in the 60's, a main source of government income has been logging. Three main logging conflicts located at Lampung (1988), Yamdena Island (1971), and North Sumatra (1989), which have not yet been resolved. The government gave licenses to the private sector for exploitation in several parts of the country. These licenses generated different civil conflicts because the central government never consulted to the local communities. In all cases, the state forces collaborated with firms to impose the will of the central government.

One of the best-known separatist organizations from Indonesia was the Free Aceh Movement, also known as GAM. In the 90's, they actively looked for the independence of Aceh territory using violence (Barter, 2015). In the most populated areas of northern Aceh, the movement offered protection to civilians against central government attacks. These attacks had the primary objective of discouraging civilians' participation in the separatist conflict. GAM gained popularity and had support from civilians and their territorial control had been translated into the provision of public services and infrastructure.

While the separatist war in Aceh accumulated thousands of deaths, it was not a national conflict (see Figure 1 for a geographical distribution of conflict incidents). Barron, Kaiser, and Pradhan (2009) argue that conflicts occur at a local level rather than at national levels like in past civil wars. They are not major crises, but they are very localized in communities of villages which can turn later into violence or civil unrest with major consequences later. The fall of Suharto in 1998 generated violence and conflict in communities and villages in provinces such as West and Central Kalimantan, Maluku and Central Sulawesi, and Jakarta. The new political system established in 1999, became a more flexible than the centralized government of Suharto. However, the political power of the Indonesian Army is still substantial. The economic and political pressure on the new government and society provoked civil unrest and conflict. Moreover, corruption and underfunding shocked government institutions, so there are few functioning institutions for conflict management (*op. cit.*).

III. Data

Our analysis is at the district-year level. Province boundaries are from 1997, which is the first year of the conflict dataset. Two provinces, Jakarta and Yogyakarta, were not included in the analysis because they cover a small and populous area where agriculture is not relevant. Data on agriculture are from BPS-Statistics Indonesia (Badan Pusat Statistik, 2017). The agricultural dataset contains wetland and dryland paddy area and total paddy production for each Indonesian district every year.

Data on weather come from two different sources. Rainfall is extracted from the Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS)[1]. CHIRPS is a global dataset that contains high-resolution satellite estimates of rainfall at 0.05° This gridded rainfall time series are improved climatology measures that help to remove systematic bias in rainfall measures, a key problem from interpolating meteorological stations data. Data on temperature are extracted from the Department of Geography of the University of Delaware. The dataset consists of monthly gridded data on precipitation interpolated to a 0.5 degree by 0.5-degree latitude/longitude grid. Both datasets are overlayed onto district boundaries to obtain district-level monthly rainfall and temperature for Indonesia.

Irrigation capacity is extracted from the Historical Irrigation Dataset (HID). This global dataset contains irrigation area data from different national and sub-national datasets. The information is used to obtain gridded data of subnational irrigated land from 1900 to 2005. We use information on the 1995 land under irrigation which occurs before the period of our conflict

[1] Available at: http://chg.geog.ucsb.edu/data/chirps/

analysis (Siebert et al., 2015). Dam data are extracted from AQUASTAT FAO dataset[2]. Each dam is described by location, nearest city, river, dam height, reservoir capacity, reservoir area, purpose of the dam (i.e. irrigation, water supply, flood control, electricity, navigation, recreation, pollution control, livestock rearing) and year of construction.

The Indonesia Conflict Monitoring System dataset from the World Bank and the government of Indonesia is used to construct conflict variables[3]. The database is a detailed survey of crime and conflict in Indonesia during the period of 1997 to 2014. The dataset is an unbalanced panel because there is no information about some provinces and some other provinces were added after 1997. Maluku Utara separated from Maluku in 1999; Kep. Bangka Belitung separated from Sumatera Selatan in 2000; Banten separated from Jawa Barat in 2000; Gorontalo separated from Sulawesi Utara in 2000; Kep. Riau separated from Riau in 2002; Papua Barat from Papua in 2003; Sulawesi Barat from Sulawesi Selatan in 2004; and Kalimantan Utara separated from Kalimantan Timur in 2012. The number of provinces corresponds to 1997 political borders. Since 1997, the number of provinces participating in the survey increased. Kalimantan Barat was the first province to participate. From 1998 to 2004, 8 provinces were part of the dataset. After 2004, the participation reached to 15 provinces while in 2012 the whole country participated the survey.

IV. Empirical Strategy

Our empirical strategy exploits the seasonal pattern of rainfall in Indonesia. Specifically, we allow rainfall and conflict to have different effects in the wet versus the dry season. Our estimating equation for agriculture is:

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[2] Available at: http://www.fao.org/nr/water/aquastat/countries_regions/IDN/

[3] Available at: http://www.worldbank.org/en/news/video/2015/08/17/indonesias-national-violence-monitoring-system

$$Y_{it} = \alpha_0 + R_{it}\alpha + X_{it}\beta + \upsilon_i + \lambda_j t_i + t_i + \varepsilon_{it} \quad (1)$$

where Y_{it}denotes the natural logarithm of wetland and dryland rice area, and production in district i and year t; R_{it} is a vector containing $R_{it}^{total}$and R_{it}^{dry} which are the measures of the intensity of rainfall in millimeters during the whole year and dry season, respectively. Given that temperature is usually correlated with rainfall, X_{it} is a vector of controls that includes the full year and dry season average temperature. To estimate the effect of rainfall on conflict, we use a distributed lag model:

$$C_{it} = \gamma_0 + R_{it}\gamma_1 + R_{it-1}\gamma_2 + X_{it}\beta_1 + X_{it-1}\beta_2 + \upsilon_i + \lambda_j t_i + t_i + \varepsilon_{it} \quad (2)$$

where C_{it} denotes the conflict outcome of interest, which is either the number of casualties or the number of conflict incidents in district i and year t[4]. The focus is on lagged rainfall because our working hypothesis is that rainfall affects conflict through agricultural production. Under this hypothesis, any effect of rainfall should not be realized until after the next harvest and potentially even later, since storage and savings may delay the effect of a bad harvest on household welfare.

The R_{it-1}^{total} coefficient γ_1 is equal to the change in conflict from an increase in precipitation measured over the course of the year; R_{it-1}^{dry} coefficient, γ_2, is equal to the change in conflict from an increase in precipitation measured over the course of a dry-season month. If rainfall is related to civil conflict through agricultural production, then the coefficients β_1 and γ_1 should have opposite signs; likewise, the coefficients β_2 and γ_2 should have opposite signs. To control for the unobservable variables potentially correlated with rainfall, our estimating equations include district fixed effects (α_i), island-year (j) fixed effects ($\lambda_j t_i$) and time fixed effects. Moreover, standard errors are clustered by district.

[4] Districts with zero conflict incidents are considered.

Equation (1) is being modified to allow for the interaction between rainfall and irrigation capacity by district in 1995. Now, Z_{it} is irrigation capacity in hectares for 1995 times climate variables. Specifically, our estimating equation for agricultural production is:

$$Y_{it} = \alpha_0 + R_{it}\alpha + X_{it}\beta + Z_{it}\delta_1 + \upsilon_i + \lambda_j t_i + t_i + \varepsilon_{it} \tag{3}$$

To estimate the effect of rainfall on conflict, we use the same strategy but now the estimating equation becomes:

$$C_{it} = \gamma_0 + R_{it}\gamma_1 + R_{it-1}\gamma_2 + X_{it}\beta_1 + X_{it-1}\beta_2 + Z_{it-1}\delta_1 + \upsilon_i + \lambda_j t_i + t_i + \varepsilon_{it} \tag{4}$$

Since irrigation might be endogenous to the presence of wealthier islands that already have better infrastructure, an instrumental variable approach using 2-stages least squares (2SLS) is used. Irrigation capacity is instrumented using the total number of dams in 1994. The specification of the first stage is as follows:

$$Z_{it} = \zeta_0 + \zeta_1 D_{it} + \upsilon_i + \lambda_j t_i + t_i + \varepsilon_{it} \tag{5}$$

Where Z_{it} is the area equipped with irrigation by province in 1995 times climate variables, and D_{it} is the total number of dams in 1994 times the weather shock variable, respectively. The same approach is followed to instrument equation (4), but using the lag of equation (5).

V. Results

Table 1 provides descriptive statistics for rainfall (by season), agricultural production, conflict- related incidents and casualties. From the first two rows of Table 1, rainfall exhibits strong seasonality. During the dry season, the districts in our sample received an average of 469 millimeters of rainfall; during the wet season, they received an average of 342 millimeters of rainfall. The average rice area by district is 32 thousand hectares while production observes an average of 139 thousand tons.

The rest of the rows of Table 1 shows descriptive statistics for the main conflict data variables during the period of analysis. Conflict is defined as violent incidents that may cause physical impact on humans or property. The average number of conflict incidents is 4.86 where 2.69 is the average number of casualties. Also, the number of damage buildings is 9 where an average of 6 were destroyed. In addition, these incidents can be classified by their purpose and participants. Popular justice and separatist incidents are the main ones while students and government agencies are the main participants.

Table 1. Descriptive Statistics

variable	Mean	Sd	Min	Max	CV
Year rainfall	469.53	287.52	0	1735.19	0.61
Dry-season rainfall	342.31	211.45	0	1213.48	0.62
Year temperature	25.23	2.34	16.21	28.84	0.09
Dry-season temperature	25.23	2.37	16.22	29.04	0.09
Rice area (000 ha)	32.12	44.18	0	680.41	1.38
Rice production (000 tn)	139.79	193.86	0	3280.35	1.39
Conflict	4.86	17.54	0	389.00	3.61
Casualties	2.69	27.66	0	1196.00	10.29
Resource incidents	0.63	2.21	0	51.00	3.49
Separatist incidents	1.10	13.51	0	389.00	12.26
Identity incidents	0.37	2.39	0	74.00	6.44
Popular justice incidents	1.82	6.97	0	196.00	3.83
Law enforcement incidents	0.93	3.06	0	48.00	3.30
Religious groups	0.13	1.47	0	61.00	11.26
Political parties	0.23	1.02	0	31.00	4.35
Separatists	1.00	12.50	0	336.00	12.50
Government	1.65	3.67	0	44.00	2.23
Students	2.35	6.45	0	97.00	2.75
Two Government agencies	0.05	0.30	0	5.00	5.53

In 1995, Indonesia had 213 dams where around 60% of them are located in Java Island, 20% in Nusa Tenggara and the rest distributed between the other provinces. Irrigation capacity is correlated with the number of dams. The more dams a province has, the more average capacity to provide irrigation. The historical most productive and wealthiest regions are the ones with more dams.

Table 2. Average irrigation capacity (ha) and number of dams by province. Year 1995

Province	mean	sd	min	max	cv	Dams 1994
Aceh	279.50	202.36	0.00	772.07	0.72	7
Bali	991.41	291.64	524.15	1506.55	0.29	2
Bengkulu	142.30	203.23	0.00	483.40	1.43	1
Jambi	116.74	140.24	0.00	495.47	1.20	0
Jawa Barat	1712.91	1012.58	0.00	3633.87	0.59	24
Jawa Tengah	1601.53	994.53	322.49	3864.49	0.62	36
Jawa Timur	1173.37	592.72	172.56	2530.13	0.51	84
Kalimantan Barat	17.14	21.63	0.00	70.67	1.26	0
Kalimantan Selat	164.09	117.53	0.00	326.59	0.72	1
Kalimantan Tenga	7.15	18.30	0.00	70.07	2.56	0
Kalimantan Timur	3.00	4.76	0.00	16.13	1.59	2
Lampung	587.94	576.40	0.00	1771.28	0.98	3
Maluku	3.84	12.62	0.00	52.40	3.28	0
Nusa Tenggara Ba	614.93	604.00	0.00	1925.09	0.98	33
Nusa Tenggara Ti	41.84	51.24	0.00	182.13	1.22	9
Papua	0.07	0.29	0.00	1.78	4.34	0
Riau	18.61	37.45	0.00	151.38	2.01	0
Sulawesi Selatan	345.77	387.28	0.00	1329.24	1.12	5
Sulawesi Tengah	60.22	47.27	0.00	145.57	0.79	0
Sulawesi Tenggar	60.77	87.66	0.00	270.14	1.44	0
Sulawesi Utara	47.90	77.96	0.00	254.32	1.63	3
Sumatera Barat	346.24	327.46	0.00	868.85	0.95	0
Sumatera Selatan	153.52	170.17	0.00	547.10	1.11	0
Sumatera Utara	158.49	202.94	0.00	748.04	1.28	3
Total	429.71	718.51	0.00	3864.49	1.67	213

Source: Irrigation –Historical Irrigation Dataset (HID), Dams - AQUASTAT – FAO

V.I. Importance of rice production: Java island

V.I.I. The effect of rainfall and irrigation on rice production

This section presents the results using the data of the districts of Java island. We want to explore the effects of rainfall and irrigation where agriculture, specifically rice, is important. Table

3 presents the model using only Java island districts. The signs of the coefficients are the expected showing that an increase in rainfall during the dry season affects production positively, but the coefficient is not significant. Rainfall over the wet season is negatively associated with production, however it is not statistically significant.

Table 3. Effect of rainfall on production in Java island

	(1) Ln(prod)	(2) Ln(yield)
Wet-season rainfall	0.000307	-0.000480
	(0.000446)	(0.000467)
Dry-season rainfall	-0.000393	0.000248
	(0.000559)	(0.000673)
Wet-season temp	-3.604***	-1.026
	(0.677)	(0.760)
Dry-season temp	2.647***	-0.0977
	(0.631)	(0.623)
Constant	36.59***	30.98***
	(5.320)	(6.429)
Observations	1,224	1,222
R-squared	0.295	0.203
Number of district_code	70	70

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1. Note: All regressions include district and year FE. Standard errors clustered by district.

Table 4 show the extended version of the model which adds the effect of irrigation instrumented with the numbers of dams in 1994. The results show that irrigation during the wet season is positively associated with production and yield, while the effect is not statistically significant. The effect of dry-season irrigation is negatively associated with production and yield. The effect of rainfall during the dry season has the same sign as in the previous estimates, but now it is statistically significant for yield.

Table 4. Effect of rainfall and irrigation on rice production in Java island

	(1) Ln(prod)	(2) Ln(yield)
Irrigation*wet-season rainfall	2.66e-08	5.61e-08
	(4.05e-08)	(4.37e-08)
Irrigation*dry-season rainfall	-9.92e-08	-1.43e-07**
	(6.04e-08)	(6.39e-08)
Wet-season rainfall	-0.000936	-0.00310
	(0.00194)	(0.00202)
Dry-season rainfall	0.00440	0.00714**
	(0.00272)	(0.00278)
Wet-season temp	-3.527***	-0.837
	(0.720)	(0.774)
Dry-season temp	2.583***	-0.257
	(0.667)	(0.623)
Constant	35.24***	30.34***
	(5.211)	(6.441)
Observations	1,224	1,222
R-squared	0.406	0.237

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1. Note: All regressions are estimated by 2SLS and include district and year FE. Standard errors clustered by district.

V.I.II. The effect of rainfall and irrigation on conflict

Table 5 shows the effect of climate variables on conflict incidents. Wet season rainfall is positively associated with conflict contemporaneously and with one lag while dry-season rainfall affects positively only contemporaneously. Overall, temperature has a positive effect on conflict while it is negatively associated with dry season temperature.

Table 5. Effect of rainfall on conflict in Java island

	(1) conflict	(2) casualties
Wet-season rainfall	0.0200***	0.00195**
	(0.00573)	(0.000781)
Dry-season rainfall	-0.0195***	-0.00254**
	(0.00701)	(0.000989)
Wet-season temp	1.291	-1.748
	(6.229)	(1.227)
Dry-season temp	-8.933	0.112
	(5.935)	(1.119)
Lag of Wet-season rainfall	0.00679**	0.00172
	(0.00337)	(0.00129)
Lag of Dry-season rainfall	-0.00456	-0.00187
	(0.00473)	(0.00126)
Lag of Wet-season temp	37.08***	0.288
	(13.47)	(2.131)
Lag of Dry-season temp	-27.15**	0.447
	(11.14)	(1.607)
Constant	-59.07	22.75
	(85.09)	(14.08)
Observations	1,190	1,190
R-squared	0.256	0.202
Number of district_code	70	70

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1. Note: All regressions include district and year FE. Standard errors clustered by district.

Table 6 presents the estimates including the effect of irrigation. The results show that irrigation is positively associated with conflict while the effect of lagged rainfall vanishes, and the contemporaneous effect of rainfall remains. The effect of irrigation through the lag of wet-season rainfall is positive and statistically significant, the rest of the coefficients are not statistically significant.

Table 6. Effect of rainfall and irrigation on conflict in Java island

	(1) conflict	(2) casualties
Irrigation*Lag of wet-season rainfall	6.36e-07*	1.01e-07
	(3.38e-07)	(9.51e-08)
Irrigation*Lag of dry-season rainfall	-5.09e-07	-4.55e-08
	(5.64e-07)	(9.40e-08)
Irrigation*wet-season rainfall	-3.01e-07	-6.09e-08
	(5.25e-07)	(9.43e-08)
Irrigation*dry-season rainfall	3.27e-07	4.07e-08
	(8.28e-07)	(1.08e-07)
Wet-season rainfall	0.0340	0.00482
	(0.0266)	(0.00413)
Dry-season rainfall	-0.0350	-0.00444
	(0.0439)	(0.00496)
Wet-season temp	-2.020	-2.490**
	(6.148)	(1.105)
Dry-season temp	-6.587	0.636
	(5.525)	(0.915)
Lag of Wet-season rainfall	-0.0237	-0.00315
	(0.0150)	(0.00368)
Lag of Dry-season rainfall	0.0196	0.000225
	(0.0287)	(0.00393)
Lag of Wet-season temp	40.38***	0.858
	(13.61)	(1.652)
Lag of Dry-season temp	-29.36***	0.105
	(11.24)	(1.300)
Constant	-42.57	26.41**
	(87.54)	(12.83)
Observations	1,190	1,190
R-squared	0.543	0.343

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1. Note: All regressions are estimated by 2SLS and include district and year FE. Standard errors clustered by district.

When we disaggregate by type of incident, the results are consistent with the aggregated version in table 5. Table 7 shows that there is a positive contemporaneous effect of year rainfall on resource, identity, popular justice and law enforcement type of incidents. Alternatively, dry-season rainfall reduces resource, popular justice and law enforcement incidents. The lag of wet-season rainfall relates positively to popular justice conflicts while dry-season coefficients show the expected sign, but are not statistically significant.

Table 7. Effect of rainfall by type of incident in Java island

	(1) resource	(2) identity	(3) Popular justice	(4) Law enforcement
Wet-season rainfall	0.00135***	4.95e-05	0.0114***	0.00723***
	(0.000480)	(0.000485)	(0.00326)	(0.00214)
Dry-season rainfall	-0.00162**	0.000275	-0.0117***	-0.00642***
	(0.000654)	(0.000920)	(0.00420)	(0.00225)
Wet-season temp	1.136	-2.006**	-5.858	8.019*
	(0.843)	(0.782)	(4.609)	(4.127)
Dry-season temp	-1.508**	0.654	-0.283	-7.796**
	(0.686)	(0.693)	(3.943)	(3.515)
Lag of Wet-season rainfall	0.000810	0.000202	0.00429**	0.00149
	(0.000528)	(0.000396)	(0.00185)	(0.00127)
Lag of Dry-season rainfall	-0.000529	0.000967	-0.00384	-0.00116
	(0.000572)	(0.00107)	(0.00290)	(0.00134)
Lag of Wet-season temp	3.366**	0.0948	22.55***	11.07***
	(1.376)	(1.039)	(8.155)	(4.143)
Lag of Dry-season temp	-2.670**	0.753	-15.05**	-10.18**
	(1.124)	(0.903)	(6.346)	(3.910)
Constant	-8.297	12.72*	-33.12	-30.38
	(7.710)	(7.182)	(52.97)	(24.82)
Observations	1,190	1,190	1,190	1,190
R-squared	0.171	0.185	0.236	0.209
Number of district_code	70	70	70	70

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1. Note: All regressions include district and year FE. Standard errors clustered by district.

Table 8 contains the extended version of the model considering irrigation. Irrigation has a positive and statistically significant effect on popular justice conflict incidents. By including irrigation, now the effect of lagged rainfall disappears, consistent with the aggregated version presented previously. The only exception is a positive effect of wet-season rainfall on law enforcement incidents.

Table 8. Effect of rainfall and irrigation by type of incident in Java island

	(1) resource	(2) identity	(3) Popular justice	(4) Law enforcement
Irrigation*Lag of wet-season rainfall	4.41e-08	7.94e-08	4.08e-07*	1.05e-07
	(4.26e-08)	(5.20e-08)	(2.15e-07)	(1.23e-07)
Irrigation*Lag of dry-season rainfall	-7.51e-08	-1.43e-07	-7.93e-08	-2.11e-07
	(5.50e-08)	(1.15e-07)	(3.55e-07)	(1.58e-07)
Irrigation*wet-season rainfall	1.52e-08	-6.80e-09	7.41e-08	-3.84e-07**
	(4.73e-08)	(7.22e-08)	(3.13e-07)	(1.81e-07)
Irrigation*dry-season rainfall	-5.53e-08	-4.01e-08	2.53e-07	1.69e-07
	(6.13e-08)	(8.78e-08)	(5.45e-07)	(2.27e-07)
Wet-season rainfall	0.000571	0.000251	0.00797	0.0252**
	(0.00218)	(0.00373)	(0.0151)	(0.0102)
Dry-season rainfall	0.00109	0.00230	-0.0244	-0.0139
	(0.00304)	(0.00444)	(0.0287)	(0.0125)
Wet-season temp	1.163	-2.081***	-6.857	5.755*
	(0.826)	(0.744)	(4.631)	(3.352)
Dry-season temp	-1.535**	0.703	0.370	-6.124**
	(0.616)	(0.552)	(3.765)	(2.946)
Lag of Wet-season rainfall	-0.00122	-0.00351	-0.0154	-0.00356
	(0.00231)	(0.00255)	(0.00996)	(0.00557)
Lag of Dry-season rainfall	0.00301	0.00778	-0.000319	0.00911
	(0.00303)	(0.00624)	(0.0183)	(0.00788)
Lag of Wet-season temp	3.696***	0.589	24.70***	11.40***
	(1.372)	(0.940)	(8.347)	(4.060)
Lag of Dry-season temp	-2.948***	0.351	-16.74**	-10.03***
	(1.134)	(0.818)	(6.604)	(3.677)
Constant	-7.937	12.37*	-24.14	-22.87
	(7.892)	(7.517)	(53.39)	(25.42)
Observations	1,190	1,190	1,190	1,190
R-squared	0.402	0.282	0.537	0.470

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1. Note: All regressions are estimated by 2SLS and include district and year FE. Standard errors clustered by district.

V.II.I. Rainfall and irrigation on agriculture in Indonesia

Table 9 shows the relationship between seasonal rainfall and rice production and yield. The signs of the estimated coefficients are the expected. An increase in overall precipitation reduces production while an increase on the dry-season rainfall affects production positively. Even though the rainfall signs go in the same direction for yield, any of the coefficients are not statistically significant.

Table 9. Seasonal Rainfall and Rice Production in Indonesia

	(1) ln(prod)	(2) ln(yield)
Wet-season rainfall	0.000148	-0.000178
	(0.000224)	(0.000252)
Dry-season rainfall	-0.000273	-9.26e-05
	(0.000291)	(0.000373)
Wet-season temp	-1.412***	0.278
	(0.430)	(0.457)
Dry-season temp	1.155***	-0.624
	(0.382)	(0.397)
Constant	18.99***	11.62***
	(2.997)	(3.752)
Observations	3,111	3,109
R-squared	0.227	0.162
Number of district_code	184	184

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1. Note: All regressions include district, island-year and year FE. Standard errors clustered by district.

Table 10 shows the extended version of the model. The estimates include the effect of irrigation instrumented by the number of dams in 1994. While the signs of rainfall coefficients remain unaltered, irrigation interacted with rainfall during the dry season has a positive impact on production and yield while it is only significant for the latter. Now, dry-season rainfall has a negative and statistically significant for yield.

Table 10. Seasonal Rainfall, Irrigation and Rice Production in Indonesia

	(1)	(2)
	ln(prod)	ln(yield)
Irrigation*wet-season rainfall	-1.54e-08	-4.20e-08**
	(1.76e-08)	(2.03e-08)
Irrigation*dry-season rainfall	2.97e-08	6.26e-08***
	(1.85e-08)	(2.29e-08)
Wet-season rainfall	0.000534	0.000841
	(0.000405)	(0.000521)
Dry-season rainfall	-0.00101**	-0.00163**
	(0.000498)	(0.000666)
Wet-season temp	-1.449***	0.225
	(0.409)	(0.435)
Dry-season temp	1.183***	-0.584
	(0.365)	(0.380)
Constant	16.89***	13.21***
	(3.050)	(3.809)
Observations	3,111	3,109
R-squared	0.493	0.205

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1. Note: All regressions are estimated by 2SLS and include district, island-year and year FE. Standard errors clustered by district.

V.II.II. Rainfall and conflict in Indonesia

Table 11 shows the effect of climate variables on conflict incidents and casualties. We find that lagged wet-season rainfall affects positively to conflict incident while dry-season rainfall reduces conflict. Temperature has a contemporaneous and positive effect on conflict and the number of casualties while it is negatively associated with dry season temperature.

Table 11. Effect of rainfall on conflict incident and casualties

	(1) conflict	(2) casualties
Wet-season rainfall	0.0164***	0.0130*
	(0.00530)	(0.00674)
Dry-season rainfall	-0.0182***	-0.0143**
	(0.00551)	(0.00705)
Wet-season temp	20.15**	17.73*
	(8.983)	(9.852)
Dry-season temp	-14.33***	-12.19*
	(5.243)	(6.833)
Lag of Wet-season rainfall	0.00536*	0.00320
	(0.00305)	(0.00269)
Lag of Dry-season rainfall	-0.00865**	-0.00532
	(0.00405)	(0.00481)
Lag of Wet-season temp	6.279	-16.28
	(12.49)	(11.04)
Lag of Dry-season temp	-8.344	14.65
	(9.180)	(10.42)
Constant	-100.2	-104.9
	(68.12)	(89.74)
Observations	3,128	3,128
R-squared	0.089	0.087
Number of district_code	184	184

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1. Note: All regressions include district, island-year and year FE. Standard errors clustered by district.

Table 12 shows the conflict variables considering the effect of the instrumented irrigation. Lagged irrigation has a positive effect on conflict while it is the contemporaneous effects are statistically significant on the number of casualties. Lagged rainfall has no effect on conflict nor casualties.

Table 12. Effect of rainfall and irrigation on conflict incident and casualties

	(1) conflict	(2) casualties
Irrigation*Lag of wet-season rainfall	2.26e-07	-1.88e-08
	(2.21e-07)	(1.85e-07)
Irrigation*Lag of dry-season rainfall	1.37e-07	2.39e-07
	(3.00e-07)	(2.99e-07)
Irrigation*wet-season rainfall	2.64e-07	-6.84e-07*
	(3.52e-07)	(3.51e-07)
Irrigation*dry-season rainfall	-1.25e-07	7.96e-07**
	(4.42e-07)	(3.79e-07)
Wet-season rainfall	0.0106	0.0286**
	(0.0101)	(0.0142)
Dry-season rainfall	-0.0155	-0.0328**
	(0.0111)	(0.0152)
Wet-season temp	20.92**	16.30*
	(8.549)	(8.903)
Dry-season temp	-14.92***	-11.29*
	(5.090)	(6.277)
Lag of Wet-season rainfall	0.000276	0.00406
	(0.00658)	(0.00673)
Lag of Dry-season rainfall	-0.0116	-0.0114
	(0.00842)	(0.0117)
Lag of Wet-season temp	4.214	-14.51
	(11.02)	(9.815)
Lag of Dry-season temp	-6.718	13.46
	(8.169)	(9.373)
Constant	-71.87	-92.39
	(62.75)	(83.94)
Observations	3,128	3,128
R-squared	0.433	0.280

Robust standard errors in parentheses *** $p<0.01$, ** $p<0.05$, * $p<0.1$. Note: All regressions are estimated by 2SLS and include district, island-year and year FE. Standard errors clustered by district.

Table 13 shows the effect of rainfall on the different type of incidents. The effect of temperature has the same sign as in table 5, however the dynamic is only statistically significant for resource, popular justice and law enforcement incidents. The lagged of dry-season rainfall shows a negative effect on popular justice incidents while lagged wet-season rainfall affects positively.

Table 13. Effect of rainfall on conflict by type of incident

	(1) resource	(2) separatist	(3) identity	(4) Popular justice	(5) Law enforcement
Wet-season rainfall	0.000780**	0.00568	0.000660	0.00539***	0.00394***
	(0.000333)	(0.00444)	(0.000524)	(0.00181)	(0.00109)
Dry-season rainfall	-0.00158***	-0.00584	-0.000742	-0.00648***	-0.00356***
	(0.000558)	(0.00450)	(0.000662)	(0.00229)	(0.00121)
Wet-season temp	2.147*	12.13	-0.222	2.039	4.057*
	(1.101)	(8.489)	(0.776)	(2.705)	(2.278)
Dry-season temp	-1.766**	-4.827	-0.311	-3.385	-4.044**
	(0.827)	(3.992)	(0.736)	(2.190)	(1.970)
Lag of Wet-season rainfall	0.000228	0.00198	0.000478	0.00214*	0.000532
	(0.000332)	(0.00240)	(0.000439)	(0.00115)	(0.000707)
Lag of Dry-season rainfall	-0.000421	-0.00413	-1.08e-06	-0.00334**	-0.000760
	(0.000403)	(0.00346)	(0.000654)	(0.00145)	(0.000826)
Lag of Wet-season temp	1.878**	-14.14	-0.807	12.74***	6.611***
	(0.786)	(10.26)	(0.944)	(3.635)	(2.149)
Lag of Dry-season temp	-2.034***	9.613	1.143	-10.34***	-6.723***
	(0.707)	(7.127)	(0.973)	(2.884)	(2.075)
Constant	-5.613	-75.01	4.852	-26.09	1.699
	(8.202)	(63.47)	(4.185)	(30.00)	(14.14)
Observations	3,128	3,128	3,128	3,128	3,128
R-squared	0.188	0.100	0.137	0.222	0.238
Number of district_code	184	184	184	184	184

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1. Note: All regressions include district, island-year and year FE. Standard errors clustered by district.

Table 14 shows the same estimates as in table 13, now including the effect of irrigation. There is only a contemporaneous irrigation effect on law enforcement incidents. However, the inclusion of irrigation shows that the lag of wet-season and dry-season rainfall has no effect on the different type of conflicts.

Table 14. Effect of rainfall and irrigation on conflict by type of incident

	(1) resource	(2) separatist	(3) identity	(4) Popular justice	(5) Law enforcement
Irrigation* Lag of wet-season rainfall	3.10e-08	-2.59e-08	-2.80e-08	1.57e-07	9.12e-08
	(3.13e-08)	(1.25e-07)	(4.01e-08)	(1.14e-07)	(6.29e-08)
Irrigation* Lag of dry-season rainfall	-1.03e-09	2.30e-07	8.66e-08	-1.19e-07	-5.97e-08
	(3.61e-08)	(1.61e-07)	(7.40e-08)	(1.67e-07)	(7.81e-08)
Irrigation*wet-season rainfall	2.18e-08	-3.39e-07	-4.69e-08	2.60e-07*	3.68e-07***
	(2.44e-08)	(2.12e-07)	(4.13e-08)	(1.49e-07)	(1.40e-07)
Irrigation*dry-season rainfall	9.13e-09	3.97e-07*	7.99e-08	-3.15e-07	-2.96e-07**
	(3.88e-08)	(2.33e-07)	(5.18e-08)	(2.18e-07)	(1.40e-07)
Wet-season rainfall	0.000303	0.0135	0.00184	-0.000704	-0.00432
	(0.000630)	(0.00886)	(0.00120)	(0.00318)	(0.00270)
Dry-season rainfall	-0.00182	-0.0150	-0.00264**	0.000926	0.00312
	(0.00122)	(0.00947)	(0.00132)	(0.00447)	(0.00279)
Wet-season temp	2.214**	11.40	-0.380	2.835	4.850**
	(1.027)	(7.864)	(0.765)	(2.468)	(2.354)
Dry-season temp	-1.805**	-4.406	-0.207	-3.978**	-4.529**
	(0.770)	(3.784)	(0.707)	(1.981)	(1.986)
Lag of Wet-season rainfall	-0.000518	0.00294	0.00118	-0.00149	-0.00184
	(0.000736)	(0.00498)	(0.00118)	(0.00261)	(0.00156)
Lag of Dry-season rainfall	-0.000322	-0.00988	-0.00207	-0.000450	0.00110
	(0.000891)	(0.00707)	(0.00168)	(0.00318)	(0.00190)
Lag of Wet-season temp	1.702**	-13.57	-0.854	11.78***	5.155***
	(0.700)	(9.318)	(0.881)	(3.042)	(1.750)
Lag of Dry-season temp	-1.915***	9.324	1.203	-9.607***	-5.723***
	(0.648)	(6.535)	(0.918)	(2.481)	(1.728)
Constant	3.158	-70.24	13.52***	-27.14	8.836
	(7.719)	(58.68)	(4.633)	(26.75)	(12.68)
Observations	3,128	3,128	3,128	3,128	3,128
R-squared	0.489	0.384	0.343	0.531	0.474

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1. Note: All regressions are estimated by 2SLS and include district, island-year and year FE. Standard errors clustered by district.

VI. Conclusions

In Indonesia, changes in rainfall patterns can be a critical factor for crops which are an important part of the Indonesian economy. During the dry season, rice production is sensitive to droughts which typically harm agricultural production. Alternatively, extreme rainfall over the wet season may also be harmful for production. The development of an irrigation network should reduce agriculture's dependence on rainfall. In our results, we find evidence that irrigation affects negatively to production and yield and increase the dependence on rainfall.

Using detailed data on conflict-related incidents published by the World Bank and gathered by the government of Indonesia, we estimate the effect of rainfall by season on agricultural production and civil conflict in Indonesia. Our results suggest that extreme rainfall will be harmful to agriculture and lead to an increase in civil conflict. Moreover, this research generates evidence that rainfall is related to civil conflict, at least in part, through its effect on agriculture.

The main results can be summarized as follows. First, we find that rainfall could be used as a measure of conflict intensity in agricultural regions like Java island. The effect of rainfall on agricultural production is realized at harvest, we would expect there to be a lag between rainfall and conflict. Second, we find that irrigation increases conflict which is opposite as the expected. A plausible explanation is the quality of the irrigation network. If the system is not well adapted to agriculture necessities, it could generate civil unrest when a weather shock occurs.

In Indonesia, it is possible to find sub-national differences in rainfall patterns that may affect conflict in some specific regions within a country. Our findings suggest that conflict incident may increase depending on the type of ongoing conflict. Moreover, our approach allows us to investigate how an irrigation network can affect conflict through rainfall. The design of a policy that weaken or prevent the impact of climate change should how these mechanisms work to generate social resilience and adaptation the natural shocks.

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