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RAINFALL PATTERNS AND HUMAN SETTLEMENT IN TROPICAL AFRICA AND ASIA COMPARED. DID AFRICAN FARMERS FACE GREATER INSECURITY?

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JEL Classification: O13, N55, N57, O44

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Rainfall Patterns and Human Settlement in Tropical Africa and Asia Compared. Did African Farmers Face Greater Insecurity?

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Abstract

We explore a new dataset of annual and monthly district-level rainfall patterns to assess the longstanding idea that climatological conditions were more conducive to the development of dense rural populations in Asia than in Africa. We test whether there existed significant cross-regional differences in both the frequency and intensity of rainfall shocks (i.e. annual mean deviations exceeding one standard deviation). Our results confirm that rainfall shocks in tropical Africa were both more frequent and more severe. Second, we test the separate effects of precipitation *levels* and *variability* on district-level population densities from colonial population censuses. We hypothesize that higher mean levels of precipitation facilitate agricultural intensification and human settlement, while unpredictability of rainfall has the opposite effect. Controlling for average rainfall levels, we find a strong negative effect of rainfall variation on population densities. This study thus lends further support to a wide literature arguing that the ecological conditions of agricultural intensification were more challenging in the African than in the Asian tropics.

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1. Introduction

Environmental conditions for sedentary agriculture have been a major determinant of the spatial distribution of the human species throughout recorded human history. Millennia ago, the world's first peasant-based civilizations emerged in major river delta's with abundant access to fresh water or in mountainous terrains where differences in altitude and associated rainfall patterns allowed for highly diverse cropping systems in a relatively confined geographical area. Of course, access to fresh water –be it through regular precipitation or stored in lakes and rivers– wasn't all that mattered for the settlement and expansion of historical populations. The spread of human and animal diseases, the location of transportation networks and trade routes, and the presence of sub-soil deposits all played their part. Moreover, changes in agricultural and transportation technology allowed some sparsely inhabited regions to become more densely settled, while degrading environmental conditions may have had opposite effects in areas that were already densely populated. Nevertheless, despite profound long-term changes in ecological and social conditions, the spatial connections between climate, agricultural development and human settlement are still visible at present (Diamond, 1997).

This paper focuses on the possible impact of rainfall patterns, and especially on rainfall variability. Adverse climatological conditions have been an oft-mentioned cause for disappointing productivity growth in African agriculture, and an important factor in explaining low historical densities of population as well as persistent poverty (Gallup et al., 1999, Sachs & Warner, 1997). Even though climates have varied over the past millennia, considerable parts of Africa such as the Sahara, parts of the Sahel, the Kalahari and parts of the East African lowlands have long been too arid to support agriculture (Mainguet, 1999; Strahler and Strahler 1992). Recent global warming seems to have compounding disadvantageous effects on conditions for agricultural production, particularly in the Horn of Africa and the West African Sahel (Verschuren et al., 2000; Giannini et al., 2008). But there are also vast areas in sub-Saharan Africa with abundant rainfall supporting the cultivation of a wide range of food and cash-crops (Tosh, 1980, p. 80).

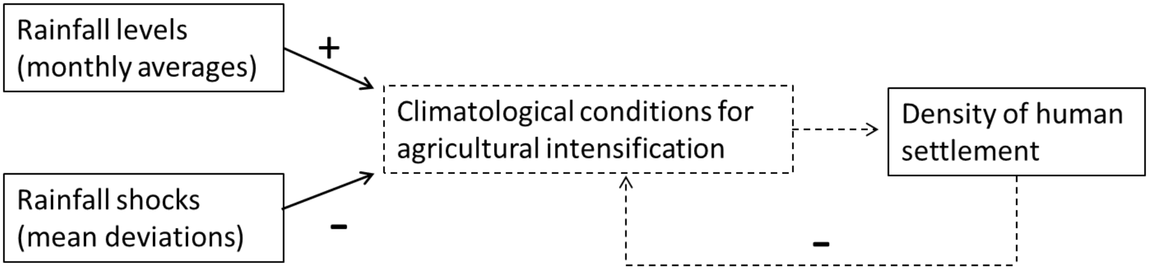
That rainfall patterns in tropical Africa may exhibit a greater degree of year-to-year variability than in other tropical areas has been given far less attention. Rainfall variability poses constraints to agricultural intensification and the growth of historical populations, even in areas where *average annual* precipitation levels support the cultivation of a large range of crops. Under predictable rainfall regimes farmers can adapt their production strategies (e.g. by cropping drought resistant crops, practicing seasonal transhumance), but when rains vary from year to year, such adaptations are more difficult to make.

Contrary to studies using contemporary climate data (Bloom & Sachs, 1998; Gallup et al., 1999; Le Blanc & Perez, 2008), this study ventures into the relationship between climate variability and human settlement in the period 1920-1940, that is, *before* the observable impact of a) anthropogenic climate change on rainfall patterns and, b) modern medical and transportation technologies on booming rural populations and increasing urbanization rates. We raise two questions. First, has rainfall, in the period before anthropogenic climate change, been significantly less predictable in tropical Africa than in tropical Asia? And if so, can this explain part of the difference in population densities that existed in both regions *before* the onset of their respective demographic booms?

We address these questions using a fine-grained dataset of historical rainfall data on a district level obtained from colonial meteorological stations. We compiled a new dataset of annual and monthly rainfall levels collected from local weather stations set up by former colonial governments for 243 districts in tropical Africa (141) and Asia (102), parts of which were drawn from earlier studies by Papaioannou (2016; 2017) and Papaioannou and de Haas (2017). We refine existing measures of rainfall variability by distinguishing the overall variation in annual rainfall (expressed in coefficients of variation picking up deviations from the mean) from the *frequency* of rainfall shocks (defined as the no. of annual mean deviations exceeding one standard deviation) and the *intensity* of rainfall shocks (the average magnitude of the deviation). We use these measures to explore whether differences between tropical Africa and Asia were sufficiently large to argue that African farmers indeed faced greater climatological insecurity.

As visualized in Figure 1, we are also interested in the impact of rainfall variability on population densities as a separate channel next to mean rainfall levels. Given the lack of reliable fine-grained data on agricultural output, we use district-level population densities taken from colonial population censuses (which we corrected for possible biases), as a proxy for conditions of agricultural intensification and associated stimuli of expanding human populations. In our regressions we control for several other factors that are likely to have impacted human settlement patterns, such as proximity to the coast, the presence of natural rivers, soil quality, malaria incidence and elevation among other things. We find that, controlling for mean rainfall levels, rainfall variability indeed explains a substantial part of the variation in population densities across tropical Africa and Asia. Since we are unable to explore the causal channel in detail, and adopt a rather static temporal framework which disregards possible negative feedback loops from increasing populations on agricultural production conditions, these tests only offer *indirect* support to the idea that climatological instability was translated into higher cultivation risks and worsened long-term prospects of agricultural development. To our defence, however, we point out that this is the first study conducted on the connection between rainfall patterns and human settlement that uses fine-grained district level data and measures of variability (frequency and intensity), both of which can be used for future research into this matter.

Figure 1. *Schematic overview of our second hypothesis*



2. Tropical agriculture and environmental conditions

To explain the principles behind economic agglomeration and concentrations of human settlement, the new economic geography literature makes a critical distinction between *first* and *second nature geography* (Krugman 1993). First nature geography refers to all environmental conditions such as climate, natural resources, natural transportation routes and so on, which jointly create advantages and disadvantages for economic and human reproduction. Second nature geography refers to the path dependence in locational choices of economic activity, by which historical accidents give rise to agglomeration effects because of the clustering of economic agents and activities in an earlier stage.

For tropical agriculture in Africa and Asia, where large concentrations of people in cities were historically scarce, first order geography has arguably been more important in explaining the variation in population densities across space before modern technologies in medicine, transportation and food conservation established conditions for unprecedented rates of population growth and urbanization. For example, it is no coincidence that Java, with its fertile, rain-fed volcanic soils became more densely populated than other islands in the Indonesian archipelago that were covered with tropical rainforest and had poorer soils. Given the importance of historical change, it is helpful to further disentangle first order 'geography' into conditions that *directly* affect the reproduction of crops, livestock and human beings, from conditions that affect *the preservation and exchange* of agricultural commodities, and related possibilities of rural-urban labour specialization.

The idea that 'geography', in the broad sense of the term, has been less conducive to productivity growth in African agriculture than in other world regions has been expressed for centuries. Adam Smith in his *Wealth of Nations* alluded to the lack of opportunities for sea-bound trade and related division of labour, as Africa had none of the great water inlets such as the Baltic or Mediterranean seas to 'carry maritime commerce into the interior parts of that great continent' (1776, p. 30, quoted in Bloom and Sachs 1998, p. 237). Fernand Braudel also emphasized the importance of environmental conditions, or 'geography', in explaining divergent development paths between Europe and Africa in the *longue durée*. According to Braudel, Africa's lack of navigable waterways inhibited the commercialisation of subsistence economies (Braudel, 1995, p. 123). The view that prohibitive transportation costs, resulting from a highly uneven spread of populations in large landlocked areas, have hampered long-term economic development in Africa, is a recurrent theme in studies of African development (Collier, 2008; Gallup et al., 1999), even though neo-institutionalists may try to reduce the role of 'geography' in explanations of global economic inequality as much as possible (Acemoglu and Robinson 2012).

Food preservation is also more challenging in warmer climates with modest seasonal variations in temperature. Gallup et al. (1999) show a strong adverse effect of tropical ecozones on the market value of agricultural output, which may lead to a productivity decrement of 30%-50% compared to temperate zone agriculture (p. 197). Without the possibility to store food in colder winters, the time between harvests and consumption of foodstuffs is shorter, limiting opportunities to transport food and produce for (distant) markets. It is also argued that farmers in tropical regions are confronted with lighter soils, facing rapid nutrient depletion in absence of artificial regeneration methods (Austin, 2008). Torrential tropical rains can cause the leaching of soil nutrients.

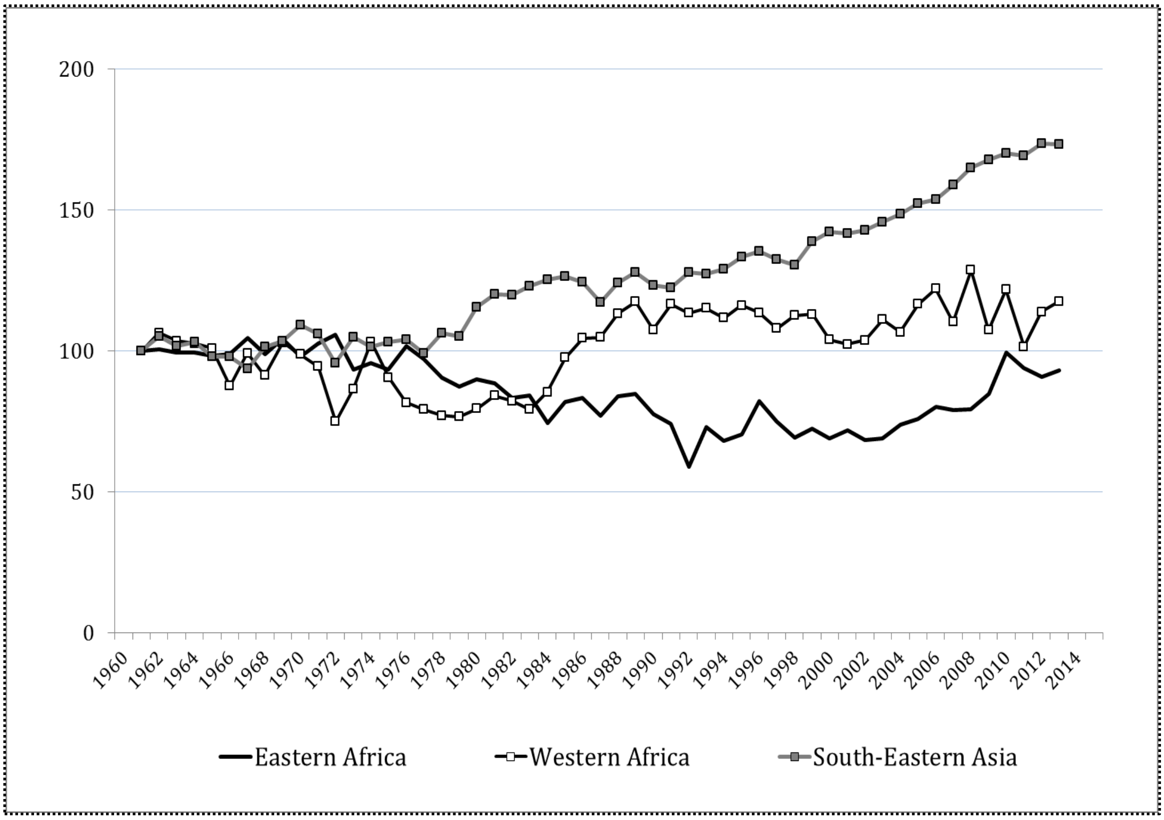
However, there is no a-priori reason why tropical soils and the complexities of food storage have put a larger constraint on agricultural development in *one tropical region compared to anther tropical region*. Neither is it evident that tropical climates inhibit agricultural development in all respects. Tropical areas are characterised by unique degrees of bio-diversity and there are many crops suitable for human consumption that grow in the tropics but cannot be grown in temperate areas. There is also no indication that conditions for crop domestication were less frequent in semi-tropical or tropical areas, although the evidence does seem to suggest that tropical regions with strong variation in elevations such as the Mexican cordillera, the Andean highlands and the Ethiopian highlands offered particular advantages for domestication efforts because of larger genetic diversity (Vavilov, 1951; Diamond 1997).

It is probable, as Diamond (1997) has famously argued, that tropical areas posed additional barriers to the diffusion of domesticated plant and animal species, as well as related agricultural innovations (see also Olsson & Hibbs, (2005)), because they require very high adaptive capacities. In particular the incidence of endemic tropical diseases has been notably worse in tropical Africa than elsewhere. Severe strains of trypanosomiasis have affected the reproduction of humans, horses and cattle, constraining the availability of animal draft power, animal manure and horseback transportation opportunities (Goody, 1980; Alsan, 2014; Frankema, 2015). Malaria and some other tropical diseases were also more severe in tropical Africa than elsewhere (Webb, 2009). These diseases had a direct effect on human reproduction, but the indirect effects were substantial as well: it hampered the human capacity to tend soils, to herd cattle, and to harvest, elaborate and exchange agricultural commodities. That higher altitudes tended to have lower rates of human and animal infection helps to explain why these areas became more densely populated than many of the disease-infected tropical lowland areas.

Technological innovations can erase barriers to agricultural productivity growth, but even then environmental factors remain important. The powerful combination of 'green revolution' technologies such as high-yielding varieties (HYVs) of rice, wheat, maize and chemical fertilizers, also require a regular supply of sunlight and fresh water to flourish. Areas with both abundant *and* predictable rains thus held a distinctive advantage over areas with low and/or variable precipitation. As the index series in Figure 2 show, gross per capita production of cereals diverged strongly under the influence of 'green revolution' technologies. The per capita output of cereals - especially paddy rice - in South-Eastern Asia had risen with ca. 75% in 2013 over 1961 levels. In Western Africa per capita production also rose, after a considerable setback in the 1970s and early 1980s, but not as impressive as in Southeast Asia, while in Eastern Africa per capita production levels have barely come back to the levels recorded in the 1960s and early 1970s.

Although differences in state capacity are often cited as a key factor in explaining why tropical Africa, contrary to large parts of tropical Asia, failed to herald a 'green revolution', it has also been acknowledged that the environmental odds were stacked against Sub-Saharan Africa in some important respects (Conway, 1998; Djurfeldt et al., 2005; Otsuka & Larson, 2013; Frankema, 2014; Booth et al., 2015). The composition of African soils appear to be more heterogeneous than elsewhere, which complicates re-generation efforts based on fertilizers (Smaling & Braun, 1996) and the vast ecological diversity and large variety in food production systems in tropical Africa has also prevented the use of 'silver bullet' HYVs, such as the IR8 rice and Norin 10 wheat varieties (Hayami et al., 1998, Hayami, 2000). The vast ecological diversity of tropical Africa, it has been argued, requires a different 'green evolution', a process of tailor-made interventions that generate lower economies of scale, and which will be more costly to effectuate (Conway 1998, Otsuka & Larson, 2013, p. vi-vii, Frankema, 2014).

Figure 2. *Index series of gross per capita cereal production, 1961-2015 (1961 = 100)*



Source: FAOSTAT, Production statistics, data retrieved at 10-05-2016; http://faostat3.fao.org/download/Q/*/E

Sub-Saharan Africa is not just generally dryer, with larger arid areas than in East and Southern Asia, rainfall patterns also tend to be more erratic (Bloom & Sachs 1998, p. 222). The unpredictability of rainfall raises risks of harvest failures and thus affects cultivation choices (e.g. preference for drought resistant crops). Indirectly, these conditions affect long-term investments in soil improvement, transportation networks and commercial infrastructures. In the past few decades the World Bank has composed drought indicators showing that a large group of tropical African countries experiences droughts more frequently and that there are significant differences in rainfall variability with other parts of the tropical world. Le Blanc and Perez (2008) have shown this statistically in a cross-country study using present-day climate data. In this paper we take this research a step further by exploring the relationship between rainfall patterns and human settlement using a more fine-grained dataset on a district level for a historical era that precedes large scale global carbon emissions and the major demographic boom in the developing world, thus avoiding a large part of the noise inherent in studies using contemporary country-level data.

3. Data

3.1 Geographical demarcation

We obtained district level data on rainfall patterns and population densities for 243 districts in 10 Sub-Saharan African colonies (141 districts) and 8 Asian colonies (102 districts) for the period 1920-1940. The areas are presented in the map of Figure 3 and listed in Table A-1. The spatial coverage of this dataset is motivated by three considerations. First, all these African and Asian colonies/countries are located between the tropics of Cancer and Capricorn.[1] Second, we selected areas in both West and East Africa to ensure that we capture sufficient intra-continental spatial variation to test our first hypothesis. Third, for reasons of data availability and data consistency, we focussed on former British colonies in which meteorological data were collected at weather stations with comparable high-frequency observations of rainfall and temperature.

Colonial administrations collected demographic data in decadal population censuses throughout the British empire. These census data, as we will highlight below, are certainly not fully reliable and many of the estimates require upward adjustment, since undercounting was common. That said, the census estimates definitely improved over time, and the estimates for the 1920s and 1930s have a (much) greater degree of accuracy than the censuses conducted in previous decades. Moreover, in view of the fact that most estimates for the 1950s and 1960s are more or less reliable, the error margins involved in adjusting the census figures through backward casting using default growth rates are relatively small (Manning 2010, Frankema and Jerven 2014). We made one exception to our focus on British colonial climate and population data by adding data for the Netherlands Indies (Indonesia), which exhibits a comparable degree of detail and accuracy, and enlarges our Asian sample.

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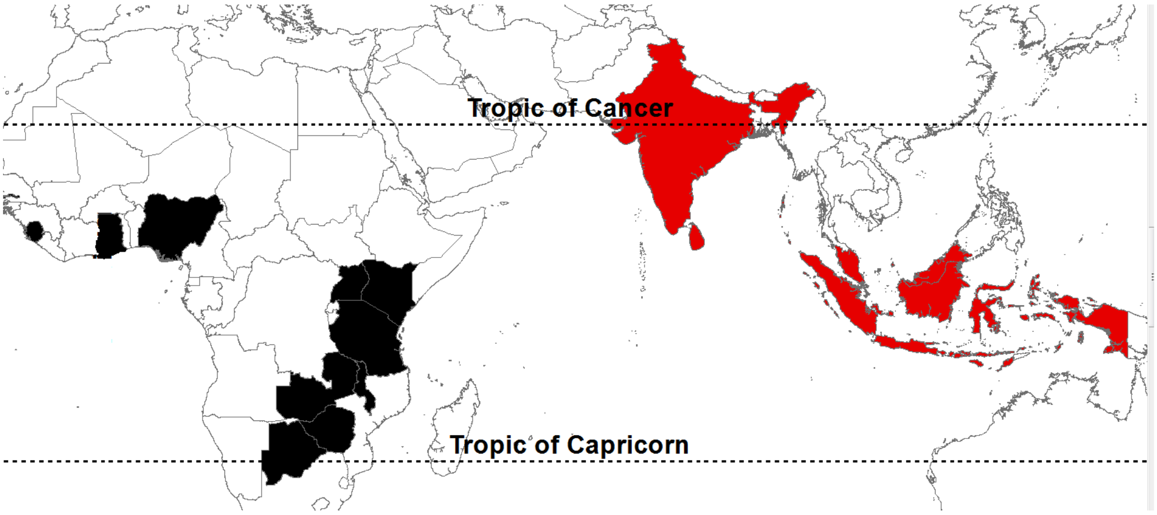
[1] Since we are interested in comparing tropical world regions, parts of northern India were excluded. As illustrated in the map above, we excluded all parts of India that are located above the Tropic of Cancer (indicated with the dotted line).

Figure 3. *Tropical Africa and Asia countries included in our sample*



Source: Created by the authors in ArcGIS.

3.2 Rainfall data

Our rainfall data were recorded at meteorological stations that were first introduced by British colonial governments in the late 19th century. The rainfall data were consistently reported throughout the period of interest and all districts included in our sample had at least one meteorological station within its borders.[2] If districts had more than one weather station, we took an unweighted average of these stations. Our main measure of weather variability is the coefficient of variation (CV) of annual rainfall, also known as relative standard deviation (RSD). This is a standardized measure of rainfall dispersion which is expressed as a percentage. It is defined as the ratio of the standard deviation σ_i to the mean μ of each district i. The values for *CV rainfall* range from 0.083 to 0.435 (and from 0.034 to 0.163 in log form).

Since there are many ways to parameterize weather variability, we also transformed our data into two additional measures, capturing the *frequency* and *intensity* of rainfall deviations from the mean. We define a *rainfall shock* as a deviation from the long-term annual mean exceeding one standard deviation. Our *frequency of shocks* measure is then defined as the ratio of years with extreme rainfall variability exceeding one standard deviation from the long-term mean (i.e. 1920-1940). The values for *frequency of shocks* range from 0.055 to 0.714 with a mean of 0.356 and a standard deviation of 0.102. In other words, the average district

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[2] While all rainfall data were obtained from primary colonial sources, data for the tropical parts of India were obtained from the Indian Institute of Tropical Meteorology (IITM) which are publicly available here http://www.tropmet.res.in/Data%20Archival-51-Page. These data have been previously used by Michalopoulos (2012) and Fenske and Kala (2015).

in our sample experienced a rainfall shock every three years or had a 35.6% annual probability of having a shock.

The *intensity of shocks* measure is defined as the sum of values exceeding one standard deviation between 1920 and 1940, and it indicates the magnitude of these shocks. The higher the intensity of the shocks, the stronger the hypothesised impact on local farming conditions and long-term patterns of human settlement. The summary statistics of the weather measures are presented in panel (a) of Table 1.

Table 1. *Summary Statistics*

Variable	Obs.	Mean	Std. Dev.	Min	Max
Panel (a): Weather measures					
Ln(Variation of Rainfall)*	243	0.082	0.023	0.034	0.163
Ln(Frequency of Shocks) *	243	0.129	0.032	0.023	0.234
Ln(Intensity of Shocks) *	243	2.013	0.339	0.718	2.580
Average Rainfall *	243	59.24	39.11	4.22	248.74
Panel (b): Population Measures					
Population (1931 census) *	221	411863	557840	1860	2539610
Land Surface (sq. miles) *	221	11871	21895	81	149277
Ln(Population Density) *	221	1.651	0.676	0.063	3.401
Adjusted Population†	221	463646	628414	2023	2876156
Ln(Adjusted Population Density) †	221	3.848	1.638	0.782	7.572
Panel (c): Controls					
Ln(Rainy Season) in months *	221	1.624	0.392	0.693	2.484
Bi-modal Rainfall Dummy *	221	0.318	0.467	0.000	1.000
Coastal Dummy¢	221	0.389	0.488	0.000	1.000
Navigable River Dummy ¢	221	0.251	0.433	0.000	1.000
Terrain Ruggedness ¥	221	0.808	0.704	0.003	3.563
Elevation °	221	674.321	565.525	9.027	2305.878
Soil organic carbon stock Φ	221	64.203	55.366	28.000	253.000
Cation exchange capacity of soil Φ	221	21.162	10.877	2.000	41.000
Malaria Stability Index Ẍ	221	9.528	8.815	0.000	32.751

Source: * indicates that these variables were assembled by the authors from primary archival sources. See Table A-3 in Appendix for an overview of the sources. *Bi-modal Rainfall:* assigned "1" for every district that has two rainy seasons within a year, and "0" otherwise.

† indicates that these variables were authors' calculations based on Frankema & Jerven (2014) and Maddison's (2010) methods. See Table A-2 in the Appendix for a detailed description.

¢ indicates that these variables were constructed by consulting FAO maps, obtained from http://www.fao.org/nr/water/aquastat/maps/index.stm. *Coastal dummy*: assigned "1" for every district located at the coast and "0"otherwise. *Navigable River dummy:* assigned "1" for every district that a navigable river runs through it and "0"otherwise.

¥ indicates that these variable were authors' calculations by consulting Nunn & Puga (2012), obtained from http://diegopuga.org/data/rugged/. *Terrain Ruggedness*: We compute the mean score of terrain ruggedness for each district in our sample using ArcGIS.

° indicates that these variables were authors' calculations by consulting Jarvis et al., (2008), obtained from http://www.cgiar-csi.org/data/srtm-90m-digital-elevation-database-v4-1. *Elevation:* We compute the mean score of these variable for each district in our sample using ArcGIS. Elevation measures the height (in meters) above mean sea level.

ɸ indicates that these variable were constructed by consulting world soil grids database, obtained from http://www.isric.org/content/data. *Soil organic carbon stock and cation exchange capacity of soil*: We compute the mean score of these variable for each district in our sample using ArcGIS. Elevation is measured in meters. Soil organic carbon stock is measured in tons per hectare for depth interval 0.05m – 0.15m. Cation exchange capacity of soil is measured in cmolc/kg at depth 1.00m.

Ẍ indicates that this variable was constructed by consulting Kiszewski et al., (2004), obtained from http://gps.ucsd.edu/faculty-directory/gordon-mccord.html. *Malaria stability index* measures the average prevalence of malaria transmission within each colonial district. The index takes into account the prevalence and type of mosquitoes indigenous to a region, their human biting rate, their daily survival rate, and their incubation period.

3.3 Population density estimates

Our population data are derived from the colonial population censuses conducted in the 1920s and 1930s, and especially the 1931 census that was held across the British empire. The difficulties of conducting accurate population counts are well-known, even for present-day governments, but especially for the poorly equipped colonial administrations of that time. The various biases in African colonial population estimates are widely acknowledged in the literature (Kuczynski, 1948; 1949, Tabutin & Schumacher, 2004, Manning, 2010; Frankema & Jerven, 2014). For the Asian colonies the data are believed to be more accurate, but certainly not flawless. For 19th century Indonesia, for instance, consecutive census estimates suggest almost impossible rates of population growth, even though the estimates for the interwar era are considered to be much more accurate.[3]

The most important problem is that colonial census data tend to underestimate actual population size because of a) a lack of census taking capacity of colonial administrations, who had to rely largely on indigenous chiefs, district officers and village headman to assemble the numbers and b) the political incentives associated with census taking efforts. As information on population size offered a crucial tool to colonial administrations to expand their tax base, respondents and local political leaders often had an

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[3] Unfortunately, we were not able to obtain consistent Indian population estimates to test our second hypothesis, due to several reorganizations of districts and other administrative boundaries that occurred in this period.

incentive to underreport – even though this wasn't always the case, since promises of subsidies related to population size sometimes had the opposite effect.[4]

That said, the capacity of colonial bureaucracies to conduct censuses did improve over time and as a result the gap between the estimated and actual number of inhabitants was substantially reduced. This is corroborated by studies pointing out that the inter-census growth rates between 1850 and 1950 were often on the high end, and in numerous cases beyond all probability. In a seminal study by Patrick Manning, a method has been proposed to backward extrapolate population estimates from the 1960s on the basis of a series of decadal default growth rates. For Sub-Saharan Africa Manning's method has been criticized and adjusted by Frankema and Jerven (2014), but their study subscribed to the basic idea of using bandwidth growth rates to adjust disputably low census estimates. But what is more important, their alternative population estimates for the 1930s don't deviate that much from Manning's, since the assumption of different default growth rates doesn't weigh so heavily in the relatively short term interval between 1950 and 1930.

We adopted this backward extrapolation method to check the population estimates in our dataset. We take the 1960 figure as the ultimate benchmark and compute the average annual growth rate between the census estimates of the 1920-1940 era in our original dataset. In line with Frankema and Jerven we assume for African colonies a default annual growth rate of 1.6 in the 1950s, 1.3 in the 1940s, 1.2 in the 1930s and 0.4 in the 1920s. We then compare these level estimates with the actual census estimates and adjust (in virtually all cases upward) the district counts with the obtained percentage. For the Asian colonies we adopt existing adjusted population series from Maddison (2010), which we also checked for population growth rates.

Making overall adjustments on a colony level and thus applying similar rates of correction to all districts within the colony, leaves us with the possible concern that the accuracy of population estimates has differed across districts. One way to correct for this is to take district level data for 1960 and then apply the backward extrapolation method on a district level. There is a great disadvantage to this method, however, as it erases the possible effects of inter-district migration. We may thus end up correcting one bias by introducing another. We thus decided against it, while knowing that the intra-colony variation in the biases of our district estimates will have to be extremely large to alter the inter-district variation we observe and this gives us considerable confidence that the data we use in the regressions are sufficiently adequate to put our main hypotheses to the test. The summary

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[4] The Nigerian census of offers a clear example for this mechanism, but that doesn't distort our estimates here, see Frankema and Jerven (2014).

statistics of population, population density and their adjusted measures are presented in panel (*b*) of Table 1. Appendix Table A-2 presents the original census estimates along with our adjusted estimates and the rates of adjustment in percentages of the original figures. Table A-3 presents the historical sources.

Unfortunately, we were not able to obtain consistent population density estimates for the Indian sample, due to the fact that several reorganizations of districts and other administrative boundaries occurred in this period. Therefore, the Indian data are use to test our first hypothesis, but are excluded from the multivariate regression we run in section 5 to test our second hypothesis.

3.4 Controls

Our second hypothesis considering the negative relationship between rainfall shocks and population density, will be tested in a multivariate regression framework. This allows us to include a number of additional controls to address omitted variable biases emerging from a range of unobserved factors that are likely to influence historical patterns of human settlement. We control for differences in general climatological conditions such as (a) average rainfall levels, (b) the length of rainy seasons (measured in months), and (c) the existence of bi-modal rainfall patterns. Additionally, we control for differences in physical geography by constructing indicators for (d) elevation, (e) soil ruggedness, (f) cation exchange capacity of soil, (g) soil's organic carbon stock, and by constructing dummies of (h) access to the coast and (i) presence of navigable rivers. The summary statistics for these controls are presented in panel (*c*) of Table 1, along with the sources used to compute them.

4. Did Africans face greater climatological insecurity?

The first part of this section (4.1) focuses on the climatological differences between the tropical areas in the two continents, questioning whether people in tropical Africa, on the whole, faced greater climatological insecurity than in tropical Asia. It presents the results of differences pertaining to the average variation of rainfall, and to the *frequency* and the *intensity* of rainfall shocks. Section 4.2 investigates whether the significant inter-continental difference we find in rainfall variability is produced by any intra-African heterogeneity, and especially a difference in climate systems between East and West Africa, or that it can be truly regarded as a general barrier to agricultural development in tropical Africa.

4.1 Climatological Differences

Figure 4 presents a scatter plot of rainfall variability (Log RainfallCV) and long-term annual average rainfall levels. We separated our 243 observations into Asian and African districts. The figure shows that the two dot clouds only partially overlap: tropical Africa is dryer than tropical Asia and the variability of rainfall is higher in Africa as well. The scatter plot also shows that the intra-continental variation in rainfall variability is larger in Africa than in Asia.

To test the statistical significance of these observations we employ a simple cross-sectional ordinary least square (OLS) regression. The model can be summarized as follows:

$$y = \alpha + \beta_1 \, Continent_i + \beta_2 X_i' + \varepsilon_i,$$

where y refers to the tree different measures of climatological variability (panel (*a*), Table 1), *Continent* is a dummy variable that takes the value of 1 if a district *i* is located in Africa and 0 otherwise (i.e. Asia is the reference category). The coefficient of interest is β_1. A positive sign, $\beta_1>0$, indicates that, on average, Africans were confronted with greater climatological instability. X_i' denotes a vector of determinants which we control for, α is a constant, and ε_i is the error term.

Figure 4. *Rainfall variation & Rainfall mean*

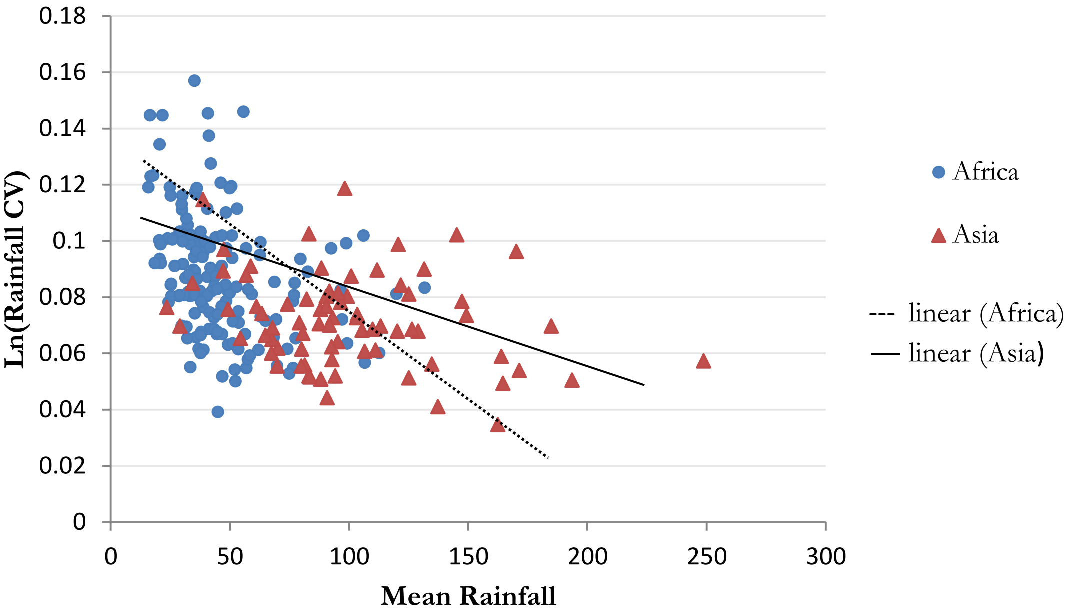


Table 2 presents the OLS estimates for the three dependent variables in turn. Columns 1-3 show the *Ln(Variation of Rainfall)* results. The Africa dummy is statistically significant at the 99% confidence interval and suggest that on average African districts, and by extension African countries, experienced higher levels of climatological variability during the 1920s and 1930s (*coeff.= 0.018, SE= 0.002, p-value= 0.000*). The results are robust to controlling for average rainfall mean (column 2), and to clustering standard errors at both the country and district level (column 3).

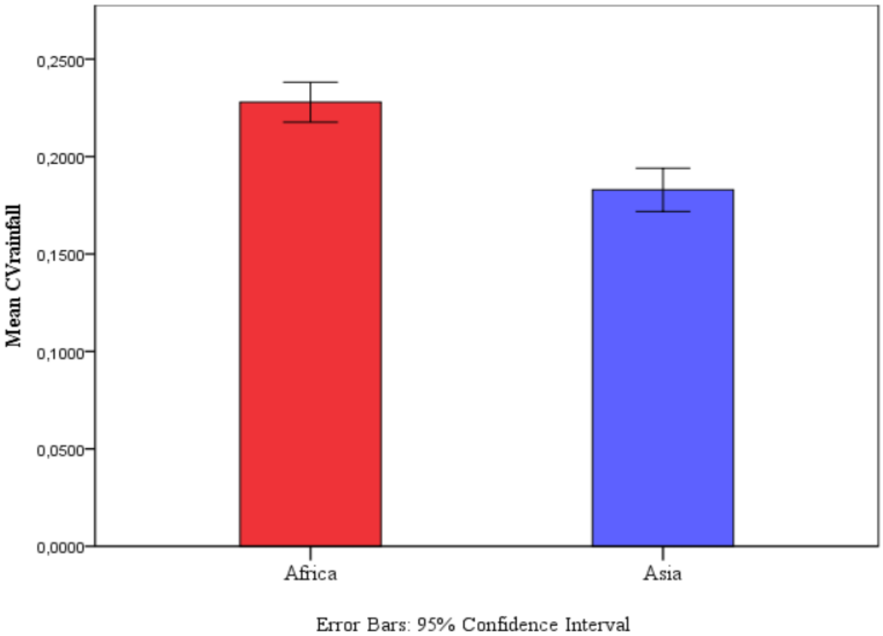
Table 2. *Rainfall Variation in Africa* & *Asia*

Dependent	Ln(Variation of Rainfall)			Ln(Frequency of Shocks)			Ln(Intensity of Shocks)		
Variables:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Africa	0.0182	0.0112	0.0151	0.0234	0.0228	0.0261	0.4232	0.5683	0.5184
	[5.43]***	[3.33]***	[4.67]***	[6.14]***	[5.79]***	[6.86]***	[8.69]***	[7.77]***	[8.11]***
Rainfall mean		-0.0013			-0.0001			0.0012	
		[-3.18]***			[-0.43]			[5.58]***	
Country effects	N	N	Y	N	N	Y	N	N	Y
F-statistic	47.80	29.96	29.51	37.72	47.80	24.16	75.53	90.08	95.34
R^2	0.153	0.189	0.201	0.143	0.143	0.146	0.271	0.381	0.438
Observations	243	243	243	243	243	243	243	243	243

Notes: Significance level at which the null hypothesis is rejected: ***, 1 percent; **, 5 percent; and *, 10 percent. Reported in parentheses are t-statistics. Standard errors are clustered at the district level, unless stated otherwise. Asia is the reference group [continent=0]. Country effects denote country dummies. The sample includes 141 districts in tropical Africa and 102 districts in tropical Asia as illustrated in Figure 3 and listed in Table A-1 in the Appendix.

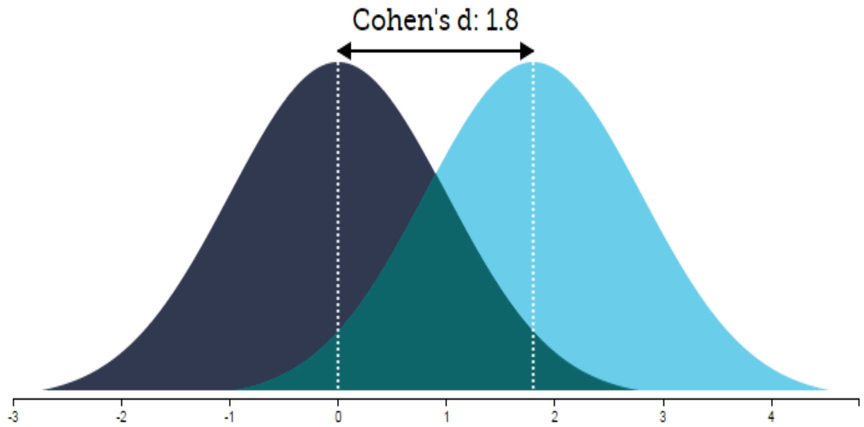
The estimated coefficients are presented graphically in Figure 5, together with the error bars set at a 95% confidence interval. It shows that the African districts in our sample experienced significantly more rainfall variation than the Asian districts. Moreover, the mean difference between African and Asian districts is large enough to be meaningful. To illustrate this, we calculated the maximum likelihood estimator (or Cohen's *d*) as a measure of effect size (Cohen, 1988). Cohen's *d* considers the standardized mean difference between two groups using the following formula: $d = (\mu 1 - \mu 2)/s$, where $\mu 1$ and $\mu 2$ are the means for the two groups (in our case Africa and Asia), and s is the pooled standard deviation. The results point to a substantial difference *d* = 1.789 (Figure 6). In other words, 96.4% of the treatment group (i.e. Africa in our case) will be above the mean of the reference group (Asia), 36.8% of the two groups will overlap, and there is a 89.9% chance that a district picked at random from the treatment group will have a higher score than a district picked at random from the control group. Taking in mind how important rainfall is for systems of rain-fed agriculture in an age where modern farming technologies were just starting to have some impact, the sheer magnitude of the inter-continental difference is a strong indication that the difference in rainfall variability had an impact on the possibilities for agricultural development.

Figure 5. *Variation of Rainfall in Africa & Asia*



Notes: Mean difference between the two continents. This figure presents the estimated coefficients of column 1 in Table 2, including error bars at 95% confidence intervals. The sample includes 141 districts in tropical Africa (left bar) and 102 districts in tropical Asia (right bar) as illustrated in Figure 3 and listed in Table A-1 in the Appendix.

Figure 6: *Visualization of effect size using Cohen's d*

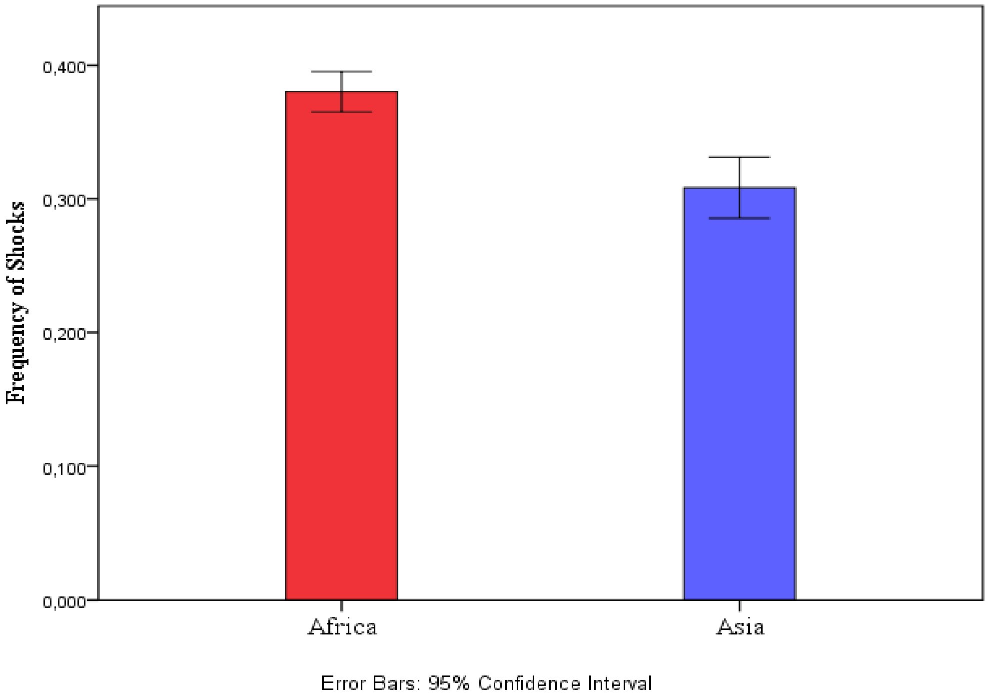


Note: Author's calculations.

Columns 4-6 in Table 2 show the *Ln(Frequency of shocks)* results. The positive and significant Africa dummy coefficient suggests that, on average, African farmers experienced a higher frequency of weather shocks than Asian farmers (*coeff.= 0.023, SE= 0.004, p-value= 0.000*). The high effect size result (Cohen's *d*= 1.724) again points to a crucial difference. Figure 7-a illustrates the mean difference between the two continents, together with the error bars. Columns 7-9 show the *Ln(Intensity of Shocks)* results. The positive and significant Africa dummy coefficient suggests that, on average, the intensity of the rainfall shocks was larger in tropical Africa, than in tropical Asia (*coeff.= 0.423, SE= 0.038, p-value= 0.000*). The large effect size (Cohen's *d*= 2.845) reveals the climatological adversities African farmers were facing compared to their Asian counterparts. Figure 7-b graphically illustrates the mean difference between the two continents, together with the error bars.

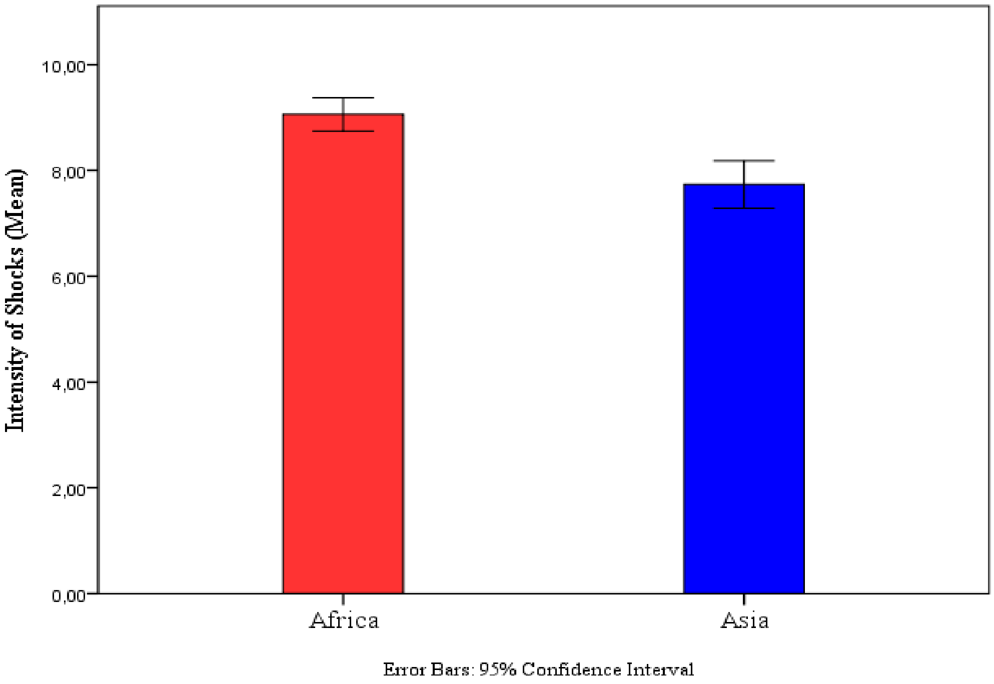
Taken together, our results indicate that rainfall shocks in tropical Africa were both more frequent and more severe than in tropical Asia, translating into higher cultivation risks. In addition, we would like to emphasize that if we would extend this cross-continental comparison with districts or provinces in former French, Belgian or Portuguese African colonies, the results would probably be even more pronounced, for the historical literature suggests that the British colonized areas with relatively favourable conditions for tropical agriculture (Burbank & Cooper, 2010, p. 315).

Figure 7-a. *Frequency of Weather shocks by Continent*



Source: Mean difference of frequency of shocks between the two continents as estimated in column 4 of Table 2. Error bars at 95% confidence interval are included. The sample includes 141 districts in tropical Africa (left bar) and 102 districts in tropical Asia (right bar) as illustrated in Figure 3 and listed in Table A-1 in the Appendix.

Figure 7-b. *Intensity of Weather Shocks by Continent*

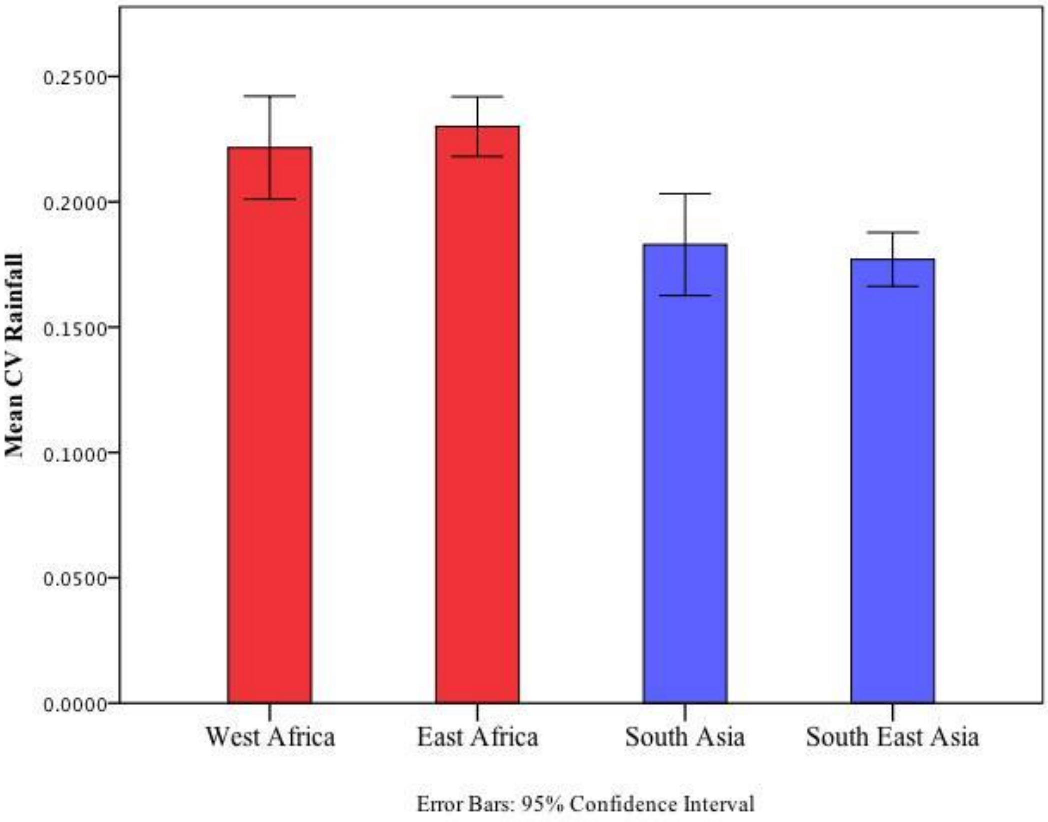


Source: Mean difference of intensity of shocks between the two continents as estimated in column 7 of Table 2. Error bars at 95% confidence interval are included. The sample includes 141 districts in tropical Africa (left bar) and 102 districts in tropical Asia (right bar) as illustrated in Figure 3 and listed in Table A-1 in the Appendix..

4.2 Intra-Regional Heterogeneity?

We now proceed by investigating whether the estimated difference between African and Asian districts is driven by any intra-African heterogeneity. To that end, we sub-divided the African and Asian samples into two groups (i.e. West and East African districts, South Asia (incl. India and Ceylon) and Southeast Asia) and ran a one-way ANOVA that compares *rainfall variation* of these groups separately.[7] Figure 8 illustrates the estimated mean differences across the four regions. While both West ($p < .001$) and East ($p < .001$) Africa exhibit significantly more rainfall variation than both Asian regions, the difference between West and East Africa is small and statistically insignificant ($p = .632$). Both African regions thus experienced significantly more rainfall variability than we observe in the Asian tropics. The results also remain largely unchanged when we only include coastal districts. Both West ($p < .001$) and East ($p < .001$) African coastal districts exhibit significantly more rainfall variation than Asian coastal districts. The difference between West and East Africa is statistically significant at 90% confidence interval ($p = .073$).

Figure 8. *Variation of Rainfall across Regions*



Source: Mean difference of rainfall variation across four regions. Error bars at 95% confidence interval.

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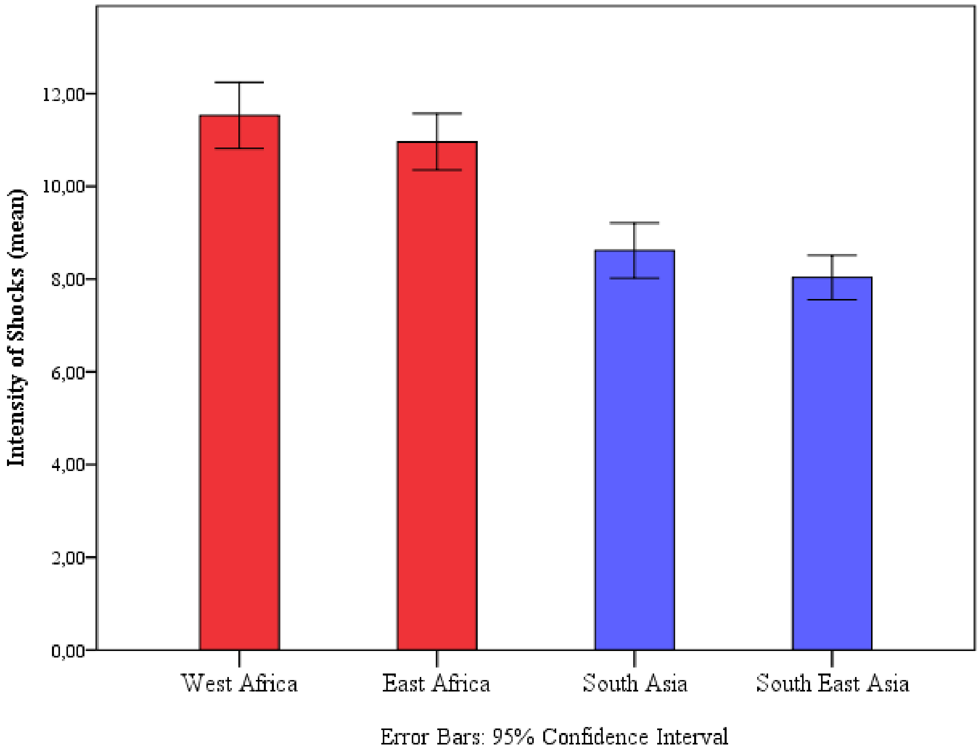
[7] Between-groups comparisons were conducted with Bonferroni corrected t-tests. We preferred this method to simple separate t-tests to avoid inflation of Type I error.

A similar method for the *frequency of shocks* result demonstrates that there is no evidence for an intra-African difference (*p* = .810), while South Asia and Southeast Asia are significantly different from both West Africa (*p* = .044 for South Asia; *p* = .032 for Southeast Asia) and East Africa (*p* < .001 for South Asia; *p* < .001 for Southeast Asia). It should be noted here that South Asian and Southeast Asian districts are not statistically distinguishable from each other (*p* = .941).

Finally, our results for the *intensity of shocks* indicate that there is a significant intra-African mean difference (*p* = .037), as is illustrated in Figure 9. West Africa experienced more severe shocks than East Africa. However, the intensity of shocks in both West (*p* < .001) and East Africa (*p* < .001) was significantly more severe than in both parts of tropical Asia (i.e. South and Southeast Asia). These findings thus underpin our argument that the Asia-Africa distinction in climatological variability is real.

Figure 9. *Intensity of Shocks across Regions*



Source: Mean difference of intensity of shocks across the three regions. Error bars at 95% confidence interval are included

5. Rainfall Variability & Population Density

We now proceed to test our second hypothesis regarding the negative relationship between rainfall variability and population densities in a multivariate regression framework. Section 5.1 presents our baseline results and section 5.2 deals with several concerns that may violate our empirical strategy in order to indicate how robust our findings are.

5.1 Baseline Results

Figure 10 shows scatter plots with mean rainfall on the y-axis and the lognormal of population densities on the x-axis. The dots represent African districts, the triangles Asian districts. Figure 10 shows that the clouds are only partly overlapping, with Asian areas generally characterized by higher average rainfall levels and higher population densities. The figure also shows a positive correlation between both variables, although the variation around the linear trend line is large. Figure 11 shows the relationship between rainfall variability and population density, again showing only a partial overlap between the clouds. Figure 11 also shows a negative relationship.

Table 3 presents our baseline OLS regression results, with rainfall shocks as the main independent variable, and rainfall means as the most important control variable. The dependent variable is adjusted population density. Column 1 shows the OLS result without any controls (*coeff.= -26.061, SE= 4.913, p-value= 0.000*). The R^2 suggests that rainfall variability explains approximately 14.4% of the variation in population density. To avoid potential multicollinearity problems, we include our controls one by one. Columns 2-7 present the results after controlling for continental differences (column 2), mean rainfall levels (column 3), length of rainy season (column 4), uni-modality of rainfall (column 5), access to the sea (column 6) and navigable rivers (column 7). Across all specifications, the results of *Ln(RainfallCV)* remain robust and statistically significant at a 99% confidence interval. Moreover, all controls yield the expected sign, which serves as an additional validation of our analysis. Finally, in column 8, we jointly include all the controls and add country fixed effect dummies. This last specification is the one we use for our conclusions, as it controls for a range of omitted variables and yields the highest R^2 of 0.346 (or 34.6%).

Figure 10. *Rainfall Mean & Population Density*

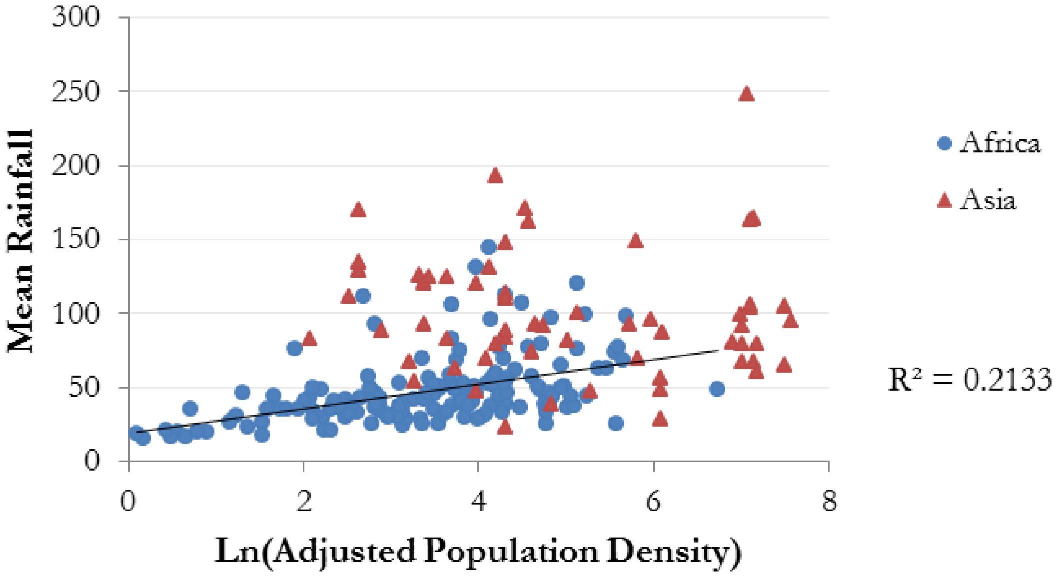


Figure 11. *Rainfall Variation & Population Density*

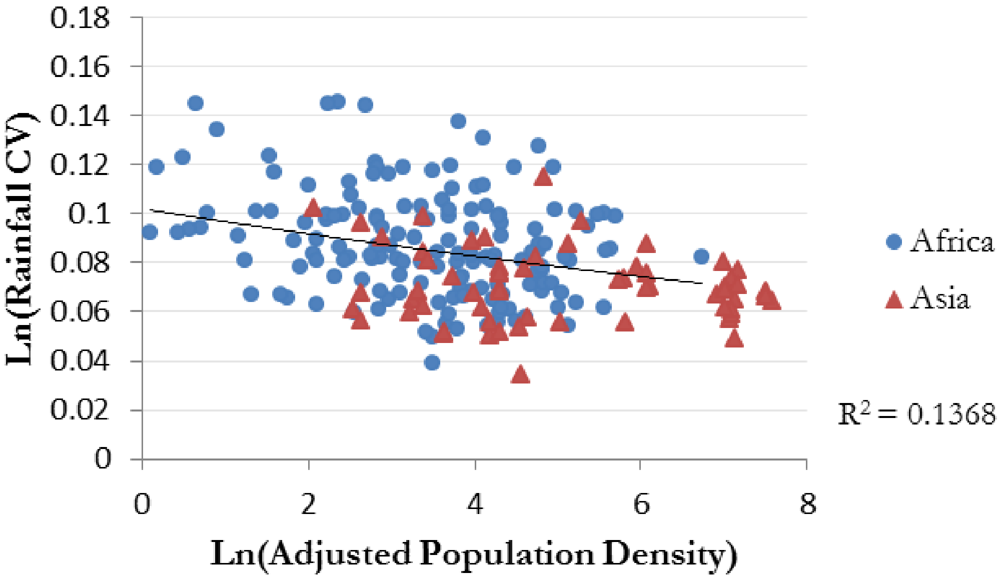


Table 3. *Rainfall Variation & Adjusted Population density in Africa & Asia*

	Dep. Variable: Log Population Density Adjusted											
	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(10)	(11)
Ln(RainfallCV)	-26.0611	-16.4612	-15.6651	-26.0933	-23.5075	-21.1884	-25.9125	-24.2716	-25.1294	-22.0478	-23.1063	-19.5801
	[-5.30]***	[-3.52]***	[-3.52]***	[-5.15]***	[-4.76]***	[-4.83]***	[-5.29]***	[-5.38]***	[-5.27]***	[-5.14]***	[-5.21]***	[-5.88]***
Africa		-0.6357										-0.2612
		[-5.32]***										[-2.01]**
Rainfall mean			0.0152									0.0091
			[5.45]***									[3.26]***
Wet season				-0.0351								-0.1293
				[-0.66]								[-1.71]*
Bi-modal rainfall					0.5432							0.4192
					[2.58]**							[2.27]**
Access to the sea						1.3264						0.2962
						[6.52]***						[1.95]*
Navigable river							-0.0821					0.0096
							[-0.37]					[-0.04]
Terrain ruggedness								0.5475				0.7413
								[3.89]***				[4.88]***
Elevation									-0.0007			-0.0006
									[-4.69]***			[-2.74]***
Cation exchange capacity										0.0667		0.0660
										[7.50]***		[5.17]***
Malaria stability index											-0.024	-0.018
											[-2.83]***	[-2.44]**
Country effects	N	N	N	N	N	N	N	N	N	N	N	Y
F-statistic	28.13	29.11	28.09	12.34	16.38	32.17	10.60	20.76	21.98	40.62	17.38	16.52
R^2	0.144	0.221	0.234	0.145	0.239	0.262	0.145	0.175	0.194	0.323	0.199	0.476
No. observations	221	221	221	221	221	221	221	221	221	221	221	221

Notes: Significance level at which the null hypothesis is rejected: ***, 1 percent; **, 5 percent; and *, 10 percent. Reported in parentheses are t-statistics. Standard errors are clustered at the district level. Asia is the reference group [continent=0]. Country effects denote country dummies. Wet season is measured in months. Bi-modal rainfall refers to the presence of two wet periods within a year. For a full description of the control variables see Table 1.

5.2 Robustness Checks

We now check the robustness of our results as reported in Tables 2 and 3. One potential concern is that the estimates are driven by outliers both in our dependent and independent variables. To deal with such concerns, we follow a conservative and strict method of excluding outliers as developed by Leys et al. (2013). In practise, we exclude any observation that exhibits a higher than 3 and lower than -3 standard deviations from the mean. The results remained largely unchanged (not reported).

Another possible concern is that the problems of undercounting in the population census of 1931 were more serious in the colonial hinterlands than in or around the capital districts, where the bureaucratic capacity required to conduct censuses was obviously higher. To check the possible impact of uneven biases in the population census, we classified the districts in our sample in three groups: 1) the capital district, 2) districts bordering the capital district and, 3) a rest category of so-called 'hinterland districts'. To correct for the possibility that undercounting was more severe in the hinterland districts, we differentiated the mark-up rates which we hitherto had applied on the colony level; we maintained the national mark-up rate for districts bordering the capital, added another 50% to hinterland districts and allocated to the capital districts whatever there was left. The results remained largely unchanged and are presented in Table A-4 in the Appendix.

6. Conclusion

Studies in the New Economic Geography have made it overly clear that the spatial distribution of economic agglomerations and associated concentrations of human settlements have deep ecological roots. Abundant and predictable rainfall is one of the key variables for explaining such settlement patterns, since rain-fed agriculture served as the basis of subsistence in pre-modern societies, and still is a highly important factor in explaining divergent trajectories of agricultural development.

This study has used a new dataset of annual and monthly district-level rainfall patterns to assess the longstanding idea that climatological conditions were more conducive to the development of dense rural populations in Asia than in Africa. Although we were not able to prove the direct causal connection of rainfall to population density, via its effect on agricultural intensification, we claim to have taken this research a step further by exploring the relationship between rainfall patterns and human settlement using a more fine-grained dataset of rainfall and population levels, and testing the impact of various measures of rainfall variability, for an era preceding large scale global carbon emissions and the demographic explosion of the second half of the 20th century. We thus managed to avoid part of the noise inherent to studies using contemporary rainfall and population data and also go beyond the level of cross-country comparisons.

Our study confirms the existence of significant cross-regional differences in both the frequency and intensity of rainfall shocks and have shown that these were not driven by any intra-African heterogeneity, even though climate systems in the tropical regions of West and East Africa are different. We also found evidence for the hypothesis that there are countervailing effects of rainfall *levels* and rainfall *variability* on the evolution of human settlements. When controlling for mean levels of rainfall, districts with greater insecurity of rains held lower population densities, and these effects were strong and robust, accounting for circa 14% of the variation. This study thus adds support to the view that the climatological challenges posed to agricultural development were larger in tropical Africa than in tropical Asia, and that this may be one of the keys to understand why large parts of tropical Asia have historically been more densely populated than tropical Africa. And in so far higher degrees of climatological variability posed more severe constraints to the adoption of modern productivity-enhancing farming technologies, this may also partially account for the diverging trajectories of agricultural development in the era of the 'green revolution'.

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Appendix

Table A-1. *Colonial Districts, c.1940*

Country	District	Country	District
Ceylon	Western Province	Tanganyika	Arusha
Ceylon	Central Province	Tanganyika	Bagamoyo
Ceylon	Southern Province	Tanganyika	Biharamulo
Ceylon	Northern Province	Tanganyika	Bukoba
Ceylon	Eastern Province	Tanganyika	Dar es Salaam
Ceylon	North-Western Province	Tanganyika	Dodoma
Ceylon	North-Central Province	Tanganyika	Handeni
Ceylon	Uva Province	Tanganyika	Iringa
Ceylon	Sabaragamuva Province	Tanganyika	Kahama
Brunei	Brunei	Tanganyika	Kigoma
Unfederated Malay States	Kedah	Tanganyika	Kilosa
Unfederated Malay States	Perlis	Tanganyika	Kilwa-Liwale
Unfederated Malay States	Trengganu	Tanganyika	Kondoa-Irangi
Unfederated Malay States	Johore	Tanganyika	Kwimba
Unfederated Malay States	Kelantan	Tanganyika	Lindi
Strait Settlements	Singapore	Tanganyika	Mahenge
Strait Settlements	Penang	Tanganyika	Masasi

Strait Settlements	Malacca	Tanganyika	Maswa
Federated Malay States	Perak	Tanganyika	Mbeya
Federated Malay States	Selangor	Tanganyika	Mbulu
Federated Malay States	Negri Sembilan	Tanganyika	Mikindani
Federated Malay States	Pahang	Tanganyika	Morogoro
North Borneo	Sandakan	Tanganyika	Moshi
North Borneo	East Coast Residency	Tanganyika	Musoma
North Borneo	Kudat	Tanganyika	Mwanza
North Borneo	West Coast Residency	Tanganyika	Newala
North Borneo	Interior Resididency	Tanganyika	Njombe
Indonesia	Serang	Tanganyika	Nzega
Indonesia	Batavia	Tanganyika	Pangani
Indonesia	Buitenzorg	Tanganyika	Pare
Indonesia	Indramajoe	Tanganyika	Utete
Indonesia	Tombo	Tanganyika	Rungwe
Indonesia	Bandoeng	Tanganyika	Shinyanga
Indonesia	Malabar	Tanganyika	Singida
Indonesia	Semarang	Tanganyika	Songea
Indonesia	Kranggan	Tanganyika	Tabora
Indonesia	Poerwokerto	Tanganyika	Tanga
Indonesia	Wonosobo	Tanganyika	Tunduru
Indonesia	Poerworedjo	Tanganyika	Ufipa-Sumbawanga
Indonesia	Magelang	Tanganyika	Usambara
Indonesia	Jogjakarta	Zanzibar	Zanzibar
Indonesia	Soerakarta	Zanzibar	Pemba
Indonesia	Soerabaja	Kenya	Digo
Indonesia	Kediri	Kenya	Malindi - Kilifi
Indonesia	Malang	Kenya	Mombasa
Indonesia	Tosari	Kenya	Lamu
Indonesia	Djember	Kenya	Kitui
Indonesia	Asembagoes	Kenya	Teita
Indonesia	Palembang	Kenya	Narok
Indonesia	Lahat	Kenya	Kajiado
Indonesia	Medanpoetri	Kenya	Machakos
Indonesia	Benkoelen	Kenya	Meru
Indonesia	Padang	Kenya	Embu
Indonesia	Sibolga	Kenya	South Nyeri
Indonesia	Padangsidimpoean	Kenya	Fort Hall
Indonesia	Koetaradja	Kenya	Nairobi
Indonesia	Pontianak	Kenya	Kiambu
Indonesia	Poetoessibau	Kenya	Naivasha
Indonesia	Bandjermasin	Kenya	Laikipia
Indonesia	Balikpapan	Kenya	Nakuru
Indonesia	Longiram	Kenya	Kericho
Indonesia	Manado	Kenya	South Kavirondo
Indonesia	Tondano	Kenya	North Kavirondo

Indonesia	Paloe	Kenya	Trans-Nzoia
Indonesia	Rantepao	Kenya	Uasin-Gishu
Indonesia	Makassar	Kenya	Nandi
Indonesia	Sindjai	Kenya	Northern Frontier
Indonesia	Ternate	Kenya	Kisumu-Londiani
Indonesia	Amboina	Kenya	Elgeyo
Indonesia	Banda	Nyasaland	Lower Shire
Indonesia	Manokwari	Nyasaland	Chikwawa
Indonesia	Merauke	Nyasaland	Cholo
Indonesia	Koepang	Nyasaland	Mlanje
Indonesia	Waingapoe	Nyasaland	Blantyre
Indonesia	Ampenan	Nyasaland	Chiradzulu
Indonesia	Singaradja	Nyasaland	Zomba
Bechuanaland	Francistown	Nyasaland	Upper Shire
Bechuanaland	Tuli Block	Nyasaland	South Nyasa
Bechuanaland	Gaberones	Nyasaland	Ncheu
Bechuanaland	Ngamiland	Nyasaland	Dedza
Bechuanaland	Serowe	Nyasaland	Ft. Manning
Bechuanaland	Lobatsi	Nyasaland	Lilongwe
Bechuanaland	Kanye	Nyasaland	Dowa
Bechuanaland	Molepolole	Nyasaland	Kota Kota
Bechuanaland	Kasane	Nyasaland	Kasungu
Bechuanaland	Ghanzi	Nyasaland	Mombera
Nigeria	Colony	Nyasaland	West Nyasa
Nigeria	Oyo	Nyasaland	North Nyasa
Nigeria	Ondo	Northern Rhodesia	Livingstone
Nigeria	Abeokuta	Northern Rhodesia	Kasama
Nigeria	Calabar	Northern Rhodesia	Mongu
Nigeria	Owerri	Northern Rhodesia	Mpika
Nigeria	Warri	Northern Rhodesia	Abecorn
Nigeria	Benin City	Northern Rhodesia	Ndola
Nigeria	Onitsha	Northern Rhodesia	Mazabuka
Nigeria	Ogoja	Northern Rhodesia	Lusaka
Nigeria	Sokoto	Uganda	Mengo
Nigeria	Kano	Uganda	Entebbe
Nigeria	Kaduna	Uganda	Masaka
Nigeria	Bornu	Uganda	Mubende
Nigeria	Yola	Uganda	Kitgum
Nigeria	Bauchi	Uganda	Bugondo
Nigeria	Zaria	Uganda	Teso
Nigeria	Ilorin	Uganda	Lango
Nigeria	Kontagora	Uganda	Toro
Nigeria	Benue	Uganda	Ankole
Gambia	Bathurst	Uganda	Kigezi
Sierra Leone	Freetown	Uganda	Gulu
Sierra Leone	Bonthe Sherbro	Uganda	Butiaba

Sierra Leone	Pujehun	Uganda	West Nile
Sierra Leone	Moyamba	India	Kerala
Sierra Leone	Kennema	India	Tamil Nadu &Pondicherry
Sierra Leone	Batkanu	India	Rayalaseema
Sierra Leone	Kaballa	India	South Interior Karnataka
Ghana	Accra	India	Coastal Karnataka
Ghana	Addah	India	Coastal Andhra Pradesh
Ghana	Quittah (Keta)	India	Telangana
Ghana	Cape Coast	India	North Interior Karnataka
Ghana	Seccondee	India	Madhya Maharashtra
Ghana	Tarquah (Tarkwa)	India	Marathwada
Ghana	Axim	India	Vidarbha
Ghana	Coomassie (Kumasi)	India	Konkan & Goa
Ghana	Sunyani	India	Chattisgarh
Ghana	Kintampo	India	Orissa
Ghana	VoltaRiver	India	West Madhya Pradesh
Ghana	Eastern Dagoma	India	East Madhya Pradesh
		India	Gurajat
		India	Jharkhand
		India	Andaman & Nicobar Islands
		India	Lakshadweep
		India	Gangetic West Bengal
		India	Saurasthtra, Kutch & Diu

Source: See main text.

Table A-2. *Population Data* & *Sources*

Country	Census 1931	Adjusted Population	Level Diff.	% Diff.
Africa		**Frankema & Jerven (2014)**		
Tanganyika	4,972,807	5,647,316	674,509	11.94%
Zanzibar	235,307	235,307	255,451	8.56%
Kenya	2,966,993	4,486,109	1,519,116	33.86%
Nyasaland (Malawi)	1,603,451	2,126,786	523,335	24.61%
Northern Rhodesia (Zambia)	1,393,258	1,781,304	388,046	21.78%
Bechuanaland (Botswana)	260,064	285,172	25,108	8.80%
Nigeria	19,928,171	24,860,435	4,932,264	19.84%
Gambia	185,150	217,034	31,884	14.69%
Sierra Leone	1,667,790	1,435,083	-232,707	-16.22%
Gold Coast (Ghana)	3,160,386	3,870,441	710,055	18.35%
Uganda	3,553,534	3,807,693	254,159	6.67%
Asia		**Maddison (2010)**		
Federated Malay States	1,770,486			
Unfederated Malay States	1,487,992			
North Borneo	277,367			
Straits Settlements	1,114,015 (+)			
Malaysia	4,649,860	4,513,000	-136,860	-3.03%
Singapore	603,163	563,000	-40,163	-7.13%
Ceylon (Sri Lanka)	5,312,548	5,312,548	5,748,000	7.58%
Brunei	30,135	31,345	1,210	4.01%
Dutch East Indies (Indonesia)	55,980,765	62,877,930	6,897,165	10,97%

Notes: See Table A-3 for sources used.

Table A-3. *Historical Sources*

The data for the British colonies in Africa and Asia were obtained from the archives of the Colonial Office in the British National Archive (TNA, London). We used information published in *Statistical yearbooks* and *Government reports*:

Africa

The Colony & Protectorate of Nigeria, *Blue Book*. Lagos: Government Printing Office, various issues.

______ *Annual Report.* Lagos: Government Printing Office, various issues,

Nyasaland Protectorate, *Blue Book*. Zomba: Government Printing Office, various issues.

______ *Annual Report.* Zomba: The Government Printer, various issues.

Sierra Leone, *Blue Book*. Freetown: Government Printing Office, various issues.

______ *Annual Report.* Freetown: The Government Printer, various issues.

The Colony & Protectorate of Kenya, *Blue Book*. Nairobi: Government Printing Office, various issues.

______ *Annual Report.* Nairobi: The Government Printer, various issues.

The Colony of the Gambia, *Blue Book*. Bathurst: Government Printing Office, various issues.

______ *Annual Report.* Bathurst: The Government Printer, various issues.

The Gold Coast Colony, *Blue Book*. Accra: Government Printing Office, various issues.

______ *Annual Report.* Accra: The Government Printer, various issues.

The Tanganyika Territory, *Blue Book*. Dar es Salaam: Government Printing Office, various issues.

______ *Annual Report.* Dar es Salaam: The Government Printer, various issues.

The Uganda Protectorate, *Blue Book*. Kampala: Government Printing Office: various issues.

______ *Annual Report.* Entebbe: The Government Printer, various issues.

Northern Rhodesia, *Blue Book*. Livingstone: Government Printing Office, various issues.

______ *Annual Report.* Livingstone: The Government Printer, various issues.

Bechuanaland Protectorate, *Blue Book*. Mafeking: Government Printing Office, various issues.

______ *Annual Report.* Mafeking: The Government Printer, various issues.

Asia

The State of Brunei, *Annual Report.* Singapore: Government Printing Office, various issues.

The State of Ceylon, *Blue Book*. Colombo: The Government Printer, various issues.

______ *Administration Report.* Colombo: The Government Printer, various issues.

The State of Kedah & Perlis, *Administration Report.* Penang: The Government Printer, various issues.

The State of Johore, *Annual Report.* Kuala Lumpur: F.M.S. Government Printing Office, various issues.

Kelantan, *Administration Report.* Kuala Lumpur: F.M.S. Government Printing Office, various issues.

The Federated Malay States, *Blue Book*. Kuala Lumpur: F.M.S. Government Printing Office, various issues.

______ *Annual Report.* Kuala Lumpur: F.M.S. Government Printing Office, various issues.

Crown colony of British North Borneo, *Blue Book*. Jesselton: Government Printing Office, various issues.

______ *Administration Report.* Jesselton: Government Printing Office, various issues.

Straits Settlements, *Blue Book*. Singapore: Government Printing Office, various issues.

______ *Annual Report.* Singapore: Government Printing Office, various issues.

The State of Trengganu, *Administration Report.* Singapore: The Government Printing Office, various issues.

Dutch East-Indies (Indonesia)

Jaarcijfers voor het Koninkrijk der Nederlanden. Kolonien = Statistics Yearbook of the Netherlands. Colonies, various issues: 1899-1923. *Publisher*: 's-Gravenhage, Belinfante.

Statistch jaaroverzicht van Nederlandsch-Indie = Statistical Abstract for the Netherlands East-Indies, various issues: 1924-1930. *Publisher:* Buitenzorg: Statistisch Kantoor van het Department van Landbouw, Nijverheid en Handel.

Indisch verslag. II, Statistisch jaaroverzicht van Nederlandsch-Indie = Indian report. II, Statistical abstract for the Netherlands East-Indies, various issues: 1931-1941. *Publisher:* Batavia, Centraal Kantoor voor de Statistiek van het Departement van Landbouw, Nijverheid en Handel.

Table A-4. *Rainfall Variation & Population Density Unevenly Adjusted*

	Dep. Variable: Log Population Density Adjusted											
	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS	OLS
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Ln(RainfallCV)	-27.7744	-18.2027	-16.9854	-27.8394	-25.5416	-22.8459	-27.5978	-26.0589	-27.5978	-27.3215	-24.156	-17.0118
	[-5.15]***	[-3.46]***	[-3.44]***	[-5.03]***	[-4.74]***	[-4.69]***	[-5.18]***	[-5.12]***	[-5.18]***	[-5.14]***	[-5.21]***	[-3.64]***
Africa		-1.2588										-0.2071
		[-5.27]***										[-1.62]
Rainfall mean			0.0158									0.0107
			[5.54]***									[3.52]***
Wet season				-0.0373								-0.1060
				[-0.69]								[-2.12]**
Bi-modal rainfall					0.4436							0.3011
					[2.00]**							[1.43]
Access to the sea						1.3422						0.9051
						[6.53]***						[1.88]*
Navigable river							-0.0990					-0.0261
							[-0.42]					[-0.11]
Terrain Ruggedness								0.5319				0.6789
								[3.48]***				[3.81]***
Elevation									-0.0007			-0.0001
									[-4.66]***			[-2.38]***
Cation exchange capacity										0.0661		0.0651
										[7.31]***		[5.65]***
Malaria stability index											-0.020	-0.017
											[-2.09]**	[-1.97]**
Country effects	N	N	N	N	N	N	N	N	N	N	N	Y
F-statistic	26.53	28.33	22.00	12.68	14.33	30.80	13.43	18.36	20.90	37.14	18.44	13.48
R^2	0.135	0.221	0.239	0.135	0.143	0.276	0.136	0.175	0.197	0.316	0.153	0.451
No. observations	221	221	221	221	221	221	221	221	221	221	221	221

Notes: Significance level at which the null hypothesis is rejected: ***, 1 percent; **, 5 percent; and *, 10 percent. Reported in parentheses are t-statistics. Standard errors are clustered at the district level. Asia is the reference group [continent=0]. Country effects denote country dummies. Wet season denotes is measured in months. Bi-modal rainfall refers to the presence of two wet periods within a year. For a full description of the control variables see Table 1.