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Climate Change and Armed Conflicts African Observatory (CACAO): a georeferenced map of Africa

Federica Cappelli[a], Caterina Conigliani[a], Valeria Costantini[a], Keti Lelo[a], Anil Markandya[b], Elena Paglialunga[a*] and Giorgia Sforna[a]

The paper develops a methodological approach to gather information on the role played by climate change in influencing armed conflicts in Africa. It builds a database to comprehensively map and analyse African countries through a geo-referenced representation of the climate, conflicts and socio-economic characteristics in a local rather than a country level analysis (110×110 km grid cells) over almost three decades, from 1990 to 2016. During this period, the African continent has been characterized by a high number of conflicts. The paper analyses the role played by climate change in affecting the conflicts dynamics, the risk of onset and magnitude, both in terms of number of registered events and fatalities. At the same time, as largely recognised in literature there are several other aspects that could aggravate (or offset) the local conditions, eventually degenerating in armed conflicts. Hence, the analysis also explores factors such as GDP, population, land use, water stress, natural resources, infrastructure availability and quality of institutions. Conflicts seem to mainly erupt in populated areas that are also rich of natural resources, but further analysis is needed in order to disentangle the role of the different drivers and to account for the spatial and temporal dependence.

Keywords: conflict, Africa, climate change, geo-referenced database.

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1. Introduction

With climate change largely recognised as a global threat, there is also growing awareness that developing countries (DCs) will suffer the most due to their greater vulnerability to damage (Moore and Diaz, 2015). The greater vulnerability of DCs to negative effects from climate change arises on the one side from their often already extreme geographical and climate characteristics, and the fact that their economic conditions are strongly linked to the availability of natural resources, such as agricultural land, available water and all types of extractable resources (Costantini et al., 2016; Antimiani et al., 2017); and on the other side from the scarcity of financial resources to implement precautionary adaptation measures to prevent climate damages.

In this respect, the Paris Agreement, reached in December 2015, aims to not only pursue global mitigation, but also strengthen the ability of countries to deal with the impacts of climate change via adaptation strategies. Nonetheless, in order to design proper measures and to quantify the amount of needed resources, a comprehensive knowledge of socio-economic processes occurring in DCs due to climate impacts is necessary.

The purpose of the present paper is to develop a methodological approach to gather information on and analyse the role played by climate change in influencing armed conflicts. In this respect, the African continent unfortunately represents a special case. The changes in temperature and rainfall patterns are expected to affect a large share of the population, influencing their decision about whether to move or migrate and contributing, in the context of scarce availability of resources and fragile institutional settings, to creating incentives for violent attacks and armed conflicts (Miguel et al., 2004; Fjelde and von Uexkull, 2012; Dell et al., 2014).

Some studies have analysed the relationships between climate, socio-economic conditions, migration and armed conflicts at the country level (Hendrix and Glaser, 2007; Marchiori et al., 2012; Maystadt et al., 2015; Daccache et al., 2015). The present paper attempts to go beyond these perspectives by developing a more granular approach that comprehensively maps African countries through a geo-referenced representation of the climate and socio-economic characteristics with respect to registered conflicts. Accordingly, we build a complete dataset for Africa that merges geo-referenced information on conflicts, geography, land use, climate change, natural resources and infrastructure availability (mostly taken from remote sensing data), with socio-economic data (such as population density, income inequality and institutional quality), covering the period from 1970 to 2016.

The paper is structured as follows: Section 2 provides a review of literature about climate change and conflicts. Section 3 and 4 describe the variables and the dataset construction process, while Section 5 provides descriptive analysis and maps. Finally, some concluding remarks are laid out in Section 6.

2. Background: climate change and conflicts

It is widely recognized that climate change affects crucial aspects of human life especially in DCs, particularly through its impacts on agriculture and food security, access to water and other resources (Markandya et al., 2017). This could worsen the already critical conditions characterizing these countries, with the risk that the resulting tensions might become armed conflicts (Weir and Virani, 2011). Indeed, even though socio-economic and institutional circumstances are crucial in explaining the onset and evolution of conflicts (Buhaug, 2010), climate change and resources endowment could become aggravating factors explaining the risk of conflicts.

During the last years a possible linkage between climate change and conflicts has been widely debated to shed light on the climate-induced dynamics leading to conflicts (Barnett and Adger, 2007; Hendrix and Glaser, 2007; Nordås and Gleditsch, 2007; Raleigh and Urdal, 2007; Burke et al., 2009; Bosetti et al., 2018).

One of the most debated aspects is related to the issue of resource scarcity induced by climate change. Natural resources represent a crucial economic source and the competition for their control may increase the risk of conflicts. As for the role of climate change, one of its main effects is an increase in temperature as well as changes in precipitation patterns which generally lead to more severe drought conditions. Moreover, there is also an increase in the frequency and magnitude of other extreme events (e.g. floods), which entail huge damages in terms of destruction of cultivated land, villages and infrastructure. Consequently, most countries, especially developing ones, suffer from a reduction of resources, especially cropland and water.

The negative impact of climate change on croplands threatens food security for all its four components, i.e., food availability, food accessibility, food utilization and food system stability (FAO, 2008). As stated by FAO, "climate change influences biophysical factors (plant and animal growth, water cycles, biodiversity and nutrient cycling), and the ways in which these are managed through agricultural practices and land use for food production. Climate variables also have an impact on physical and human capital (roads, storage and marketing infrastructure, houses, productive assets, electricity grids, and human health), which indirectly changes the economic and socio-political factors that govern food access and utilization and can threaten the stability of food systems" (FAO, 2008, pag. 11), intensifying the risk of competition for necessary, but limited, resources (Wischnath and Buhaug, 2014; Raleigh et al., 2015).

Water access is another widely debated crucial issue and several studies have investigated the link between conflicts and climate-induced water scarcity (Mwiturubani, 2010; Brochmann and Gleditsch, 2012). In particular, the risk of competition for the access to fresh water is very high (Codjoe and Larbi, 2016). In this respect, DCs remain highly dependent on rain-fed agriculture for both employment and economic production and the zones without an irrigation system are found to be the most exposed to the risk of conflicts as a consequence of climatic variations (von Uexkull, 2014; Daccache et al., 2015). According to Mwiturubani (2010), in addition to water access, conflicts over water also occur as a struggle to utilize the scarce resource[1]. This study argues that conflict for both water access and use may occur at the household level (e.g. gender issues), at village level (e.g. members of a village can access water at a nearby village, intensifying water scarcity) and between livelihood systems (e.g. between people practicing different economic activities).

Some studies also investigate how temperature and precipitation variations influence the probability of conflicts through changes in features and properties of both pastoral zones (Meier et al., 2007; Doti, 2010) and water basins (Onuoha, 2010; De Stefano et al., 2017), thus altering pastoral livelihoods and fishing activities. For example, Onuoha (2010) simultaneously describes these dynamics by analysing the effects of climate change on Lake Chad, which represents the main source of freshwater for drinking and sanitation, as well as for economic activities (agriculture, fishing and pastoralism) for four African countries. Owing to climate change, the lake has lost over 50 per cent of its water during the last 40 years, leading to a reduction of fish stock, water availability and a loss of vegetation and land. This study argues that the reduction of Lake Chad has contributed to the eruption

1: Water-use conflicts occur when one water source is used for more than one use by different users and the uses are not complementary (Mwiturubani, 2010).

of violent conflicts over competition for diminishing water resources, by intensifying the pattern of migration and the contact between major livelihood systems.

However, the availability of natural resources alone does not necessarily prevent conflicts. An example relates to a situation in which a large share of national wealth is derived from few economic activities or industries connected with the exploitation of (abundant) natural resources. Indeed, this entails the risk of neglecting other sectors (Auty, 1993) or a fair distribution of the revenues derived from the exploitation of these resources, with the possibility of being trapped in the so-called resource curse. Among the several studies analysing these dynamics, Cilliers (2009) and Holmberg (2008) show that in poor countries with high natural resources endowment, controlling and exploiting processes for those resources are likely to result in environmental crisis and civil conflicts. Ayodele (2010) highlights how oil exploration in Nigeria has increased environmental degradation, due to gas flaring, oil and water pollution, bush burning and CO_2 emissions. This has led to severe consequences in terms of poverty and human development, as well as increasing the civil conflicts. Ross (2004) reviews several studies on natural resource and civil war links and suggests that oil production and exports increase the likelihood of (the onset of) conflicts, due to the rent-seeking behaviour that could give further financial incentives to increase conflict, especially in case of capital-intensive processes, where the state and extraction firms gain more benefits than local unskilled workers. Although similar mechanisms may be expected to apply also in case of non-fuel minerals, this issue has received much less attention, especially in quantitative terms.

Finally, it is worth noting that climate change is characterized by a high level of uncertainty (Markandya, 2014), so that uncertainty about the availability of resources in the future can be a cause of conflict in the coming years. In this respect, Mwangi (2010) investigates the case of Lesotho, which is characterized by abundant water exported to South Africa. Nevertheless, scenarios indicate that the country will in future suffer from water stress and scarcity as a result of climate change. This creates the potential for future interstate conflicts as Lesotho may be unable to supply adequate water to South Africa. The study concludes that the main challenge for Lesotho "currently lies in the management of its water resources". Accordingly, there is the need for good institutions that would improve water management in order to reduce the degradation of water sources and enhance equitable access to and utilisation of the resource (Mwiturubani, 2010).

Indeed, the quality of institutions plays a crucial role in affecting conflict dynamics (Gizelis and Wooden, 2010). All the aspects previously described can be aggravated by the absence of proper institutional settings. Good institutions are essential for an effective use of resources as well as to cope with adverse socio-economic conditions and to implement adaptation policies limiting the vulnerability to climate change. The more a country is vulnerable to climate change, the more is its exposure to these risks, especially if the focus of the economy is on a few climate-dependent sectors, as in the case for many DCs. In this respect, we focus our analysis on African countries as they represent an emblematic case. Many of them already suffer from food insecurity, access to water, economic development and political tensions. They are also characterized by a very high vulnerability to climate change (and low adaptive capacity), together with scarce institutional quality and an economic structure mainly reliant on climate-dependent sectors. Accordingly, the impacts of climate change represent a serious threat for the entire economic system and an obstacle for future development (Castells-Quintana et al., 2017) and the risk of conflicts (as a consequence of climate–induced resource scarcity) can be particularly high.

While, as noted, several studies have analysed the links between climate change, conflicts and other socio-economic factors at the country level, there is a need to look at a more disaggregated scale and recently more efforts have been directed to sub-national and other geographically more disaggregated analysis. This allows the within-country variation to be accounted for as well as the difference in vulnerability among spatial areas, independently from the administrative boundaries. By this means, one can better disentangle the risk of exposure to physical hazards from the actual impact on human population (Busby et al., 2014).

Within the African continent, most of the studies based on geo-referenced analysis have focused on East Africa with the literature largely accounting for variations in the precipitation patterns and, more recently, temperature change. In some cases, a link is found between increasing temperature or decreasing precipitation and armed conflicts (Hsiang et al., 2011; Ember et al., 2012; Fjelde and von Uexkull, 2012; Hendrix and Salehyan, 2012; O'Loughlin et al., 2012; Raleigh and Kniveton, 2012; Maystadt and Ecker, 2014), while in other cases no significant impacts emerge (Buhaug, 2010; Theisen et al. 2011; O'Loughlin et al., 2012; Theisen, 2012).

Raleigh and Kniveton (2012) gather data for Uganda, Ethiopia and Kenya from 1997 to 2010 and their results show that with increasing rainfall variability (from monthly 2.5° grid data), the frequency of small-scale conflicts increases. Using a 1° gridded analysis covering precipitation and temperature anomalies, O'Loughlin et al. (2012) analyse several countries in East Africa (Burundi, Djibouti, Eritrea, Ethiopia, Kenya, Rwanda, Somalia, Tanzania and Uganda) from 1990 to 2009. They highlight that higher temperature raises the risk of violence while wetter precipitation deviations have a mitigating effect (on the conflict risk), but their results do not support the inverse relationships (that a lack of rain would raise conflict risk) and drier and normal periods show no effects on the risk of conflicts. They further highlight the relevance of contextual conditions as pastoralist and non-pastoralist agriculture and other geographic, socioeconomic and political factors.

Ide et al. (2014) focus on Kenya and Uganda and try to answer to the question about where the link between climate change and violent conflicts is most likely to occur. They consider three dimensions: exposure (higher temperatures and reduced precipitation), vulnerability (e.g. education, health, political instability, environmental dependence, population density and soil degradation) and violent conflict risk (GDP and democracy level, population density and previous conflicts); and combine them in a composite risk index (CRI) for 2008 with a spatial resolution of 0.5°.

Maystadt et al. (2015) build a grid-cell resolution (0.5°) dataset for North and South Sudan from 1997 to 2009 to analyse the impact of precipitation and temperature anomalies on violent conflicts, and find the latter to be particularly strong. They also suggest that water scarcity (as an example of competition over natural resources) is an aggravating factor in the climate-conflicts relationships, especially in pastoralism-dependent regions.

A more comprehensive analysis with respect to the geographical coverage is provided by Harari and La Ferrara (2018). They build a dataset at the sub-national level for Africa over the period 1997–2011 where the cross-sectional units are structured as a raster grid with 1° latitude and longitude resolution cells. They analyse the relationship between conflicts and climate change focusing on the role of agriculture as main channel in the link between weather shocks and the worsening of socio-economic conditions. The spatial analysis is at the sub-national level where the incidence of civil conflicts in a cell is explained not only in terms of climate indicators from the cell itself, but also controlling for spatial correlation in the covariates (with respect to neighbouring cells) and autocorrelation in the dependent variable, both in time and space. This appears to be the first empirical study where the persistency in the occurrence of civil conflicts and the possibility of conflict spillovers across geographical units are accounted for, in line with the "conflict trap", according to which "once a country has had a conflict it is in far greater danger of further conflict" (Collier, 2003).

3. Database description

In order to address some of the climate-conflict related issues previously described and take the several complex dynamics into account, we build the *Climate Change and Armed Conflicts African Observatory (CACAO)*, a comprehensive georeferenced database for Africa that combines conflict data with climate and socio-economic information resulting in a georeferenced panel database for the entire African continent[2] covering the period from 1990 to 2016.

Accordingly, the cross-sectional panel dimension is given by dividing the African continent in georeferenced cells, according to a grid map with 1°×1° spatial resolution (approximately 110×110 km).

With respect to the variables included in the database, they can be grouped in the following classes:

1. georeferenced and time variant (conflicts, climate, GDP and population);
2. georeferenced and time invariant (natural resources and geographical characteristics);
3. country level and time variant (national economic structure and institutional quality).

Within the first class of variables, data on armed conflicts come from the UPPSALA-UCDP Georeferenced Event Dataset (GED) Global version 17.1 (2016)[3], which provides data for 45 African countries[4] (the number of overall registered events is 35,437) from 1989 to 2016 (Sundberg and Melander, 2013; Croicu and Sundberg, 2017). The unit of analysis is an individual incident of lethal violence occurring at a given time and place. Conflict events included in the database are defined as incidents "*where armed force was used by an organised actor against another organized actor, or against civilians, resulting in at least 1 direct death at a specific location and a specific date*" (Croicu and Sundberg, 2017, pag. 2). The organized actor can be the government of an independent state as well as a group either formally or informally organized and a death is classified as direct if registered among warring parties or as violence against civilians. Incidents are included in the database if they resulted in the death of at least one person, with an incident related threshold of 25 deaths per year to differentiate between active and non-active years.

Furthermore, depending on the organized actors involved, there are three different types of conflicts: state-based (where at least one of the primary parties is the government of a state), non-state conflicts (among similarly organized groups) and one-side violence (where one of the two sides is always unorganized civilians) [5].

2: The 48 countries included are: Algeria, Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Central African Republic, Chad, Congo, Cote d'Ivoire, Democratic Republic of Congo, Djibouti, Egypt, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea Bissau, Kenya, Lesotho, Liberia, Libya, Madagascar, Malawi, Mali, Mauritania, Morocco, Mozambique, Namibia, Niger, Nigeria, Rwanda, Senegal, Sierra Leone, Somalia, South Africa, Sudan, Swaziland, Tanzania, Togo, Tunisia, Uganda, Zambia, Zimbabwe. Benin, Equatorial Guinea, Gabon, Gambia and Malawi have been included even if no conflicts have been registered for these countries in the UPPSALA-UCDP, while we excluded island countries (Cape Verde, Comoros, Mauritius, São Tomé and Príncipe, Seychelles). South Sudan has been included as Sudan.

3: Only events linkable to a UCDP/PRIO Armed Conflict, a UCDP Non-State Conflict or a UCDP One-Sided Violence instance are included.

4: The following African countries are not included: Benin, Cabo Verde, Equatorial Guinea, Gabon, Gambia, Malawi, Mauritius, São Tomé and Príncipe, Seychelles.

5: A formally organized group is a non-governmental group, with announced name, that uses armed force as the result of conscious and planned political campaigns (as in opposition to spontaneous violence). On the other hand, a group is defined as informally organized if (without an announced name) is involved in a clear pattern of connected violent incidents (non-state conflict) in which both groups at war use armed force against the other. Accordingly, non-state armed conflicts only consist of formally versus formally organized groups or informally versus informally organized groups, while a formally organized

Accordingly, we have constructed several variables representing different conflict-related characteristics for each grid-cell (represented by the identified *id grid*). First, a dummy variable (*cd*) has been introduced, assuming the value of 1 if in the grid cell/year at least one conflict has been registered, and 0 otherwise (no conflicts registered). Second, since more than one conflict could have been registered in the same grid cell and year, a second variable (*nc*) records the number of conflict events per grid cell/year (e.g. to help controlling for the actual onsets of new conflicts). Third, we have included the overall number of deaths per cell per year, as sum of all the fatalities reported in all conflicts registered in the same grid cell per year (*nd*).

The second set of data is climate and climate change related. It also belongs to the set of georeferenced and time variant variables. In this case, data are collected from Princeton University that, in collaboration with ICIWaRM and UNESCO-IHP, has developed the African Flood and Drought Monitor (and forecasting system) providing georeferenced data for Africa at 0.25° grid resolution[6]. In this case, we first take monthly data from 1990 to 2016 on maximum and minimum temperature, precipitation, and standard precipitation index and then we calculate the yearly average. Accordingly, the following variables have been recorded:

1. Annual Average Temperature: measured at two meters above the surface and calculated as the mean between minimum and maximum annual temperature resulting from averaging monthly data. Data from 1990 to 2008 rely on the Princeton Global forcing methodology while from 2009 to 2016 on Global Forecasting System Analysis. Original data expressed in the Kelvin scale have been converted in in Celsius (centigrade) degrees;
2. Annual Average Precipitation: expressed as daily total surface precipitation, in mm/day. Data from 1990 to 2008 rely on the Princeton Global forcing methodology while from 2009 to 2016 on Satellite Precipitation (3B42RT);
3. Annual Average SPI-12: Standard Precipitation Index indicating deviations from long-term normal rainfall during the 12 preceding months for each month (ranging from -3.719 to +3.719); this is taken as index of meteorological drought and lower values represents dry conditions; in some cases, has been taken as indicator of rainfall anomalies, as in Fjelde and von Uexkull, 2012).

For each of these variables, we also include the average values and (except for the SPI-12) the corresponding standard deviations with respect to the previous 5 and 10 years. Accordingly, 13 variables represent climate characteristics and climate change in medium-term.

The third class of georeferenced and time variant information is given by data on GDP and population from the Global Gridded Geographically Based Economic Data (G-Econ)[7] and the UN-Adjusted Population Count database[8] respectively, both provided by the Socioeconomic Data and Applications Center (SEDAC). In addition to the GDP and population level in the current year (expressed, respectively, as thousands of US dollar PPP constant 2005 and population number), we also consider the GDP per capita, the lagged value for both GDP and GDP per capita and the percentage change of GDP per capita with respect to the previous year. Such data are classified on the basis of a geo-referenced grid with a cell extension of about 110×110 km which represents our reference grid.

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group cannot be fighting an informally organized group to keep non-state conflicts and one-sided violence as independent categories.

6: http://stream.princeton.edu/AWCM/WEBPAGE/interface.php?locale=en

7: http://sedac.ciesin.columbia.edu/data/set/spatialecon-gecon-v4

8: http://sedac.ciesin.columbia.edu/data/set/gpw-v4-population-count-adjusted-to-2015-unwpp-country-totals

The next class of variables (georeferenced but time invariant) includes information on natural resources, land use and water and water stress. To control for geographical and spatial characteristics, we include a list of georeferenced time-invariant variables to describe the country endowment in terms of natural resources, infrastructures, land cover and vegetation. More specifically, information on natural characteristics as water stress and land cover (such as agriculture, forests, grasslands, artificial surfaces, developed areas, and vegetation across the landscape) has been gathered. Another type of geo-referenced data included provides information on infrastructure, energy and natural resources related activities as: railways, roads, crude oil refineries and pipeline, electricity generating power plants (coal, gas and oil).

Accordingly, to control for the resources availability (abundance/dependence), we introduce 3 dummy variables representing if in the grid cell has been registered the presence of:

1. mineral and fossil resources (mines and power generating units): data used to build this dummy variable include the presence of crude oil refineries, coal power plants, gas and oil power generating units[9]; oil pipelines[10]; mineral operations (available from the Data Basin Dataset that records mineral facilities as mines, plants, mills or refineries of aluminium, cement, coal, copper, diamond, gold, iron and steel, nickel, platinum-group metals, salt, and silver, among others)[11];
2. forest (Global Land Cover dataset, MODIS-based Global Land Cover Climatology)[12];
3. rural areas (Global Land Cover dataset, MODIS-based Global Land Cover Climatology).

Variables 2 and 3 have been coded considering the data from the MODIS model (Broxton et al., 2014), which provides a map on land cover classification over the period 2001–2010, using, for each grid cell, the land cover type with the highest overall confidence in the period. In particular, we recoded the original land cover classes in 8 aggregates as reported in Table 1.

Table 1: Land cover classification

Land cover	**Classification**
Water Permanent Wetland Snow and Ice	Water
Evergreen Needle leaf Forest Evergreen Broadleaf Forest Deciduous Needle leaf Forest Deciduous Broadleaf Forest Mixed Forests	Forest
Closed Shrublands Open Shrublands	Shrublands
Woody Savannas Savannas	Savannas
Grasslands	Grasslands
Croplands Cropland/Natural Vegetation Mosaic	Rural
Urban and Built-Up	Urban
Barren or Sparsely Vegetated	Desert

9: http://worldmap.harvard.edu/maps/11880
10: http://worldmap.harvard.edu/maps/pipelines
11: http://www.arcgis.com/home/item.html?id=a937c3c7faf241fe91155db49623ea2c
12: https://landcover.usgs.gov/global_climatology.php

For the water dimension, we take as reference the Aqueduct Water Risk Atlas[13], which makes use of a framework of 12 (time invariant) global indicators grouped into three categories of risk and one overall score, including indicators of water quantity, water variability, water quality, public awareness of water issues, access to water and ecosystem vulnerability (see Table A.6 for further details). We included the following variables:

1. Baseline Water Stress: measures total annual water withdrawals (municipal, industrial, and agricultural) expressed as a percent of the total annual available flow (this is calculated as the ratio between yearly total water withdrawals and the mean available blue water between 1950 and 2008)[14];
2. Inter-annual Variability: measures the variation in water supply between years and is calculated as the ratio between standard deviation of total blue water and the mean of total blue water (1950–2008);
3. Seasonal Variability: measures variation in water supply between months of the year and it is calculated as the standard deviation of monthly total blue water divided by the mean of monthly total blue water (1950–2008)[15];
4. Flood Occurrence: is the number of floods recorded from 1985 to 2011;
5. Drought Severity: measures the average length of drought times the dryness of the droughts from 1901 to 2008. Drought is defined as a contiguous period when soil moisture remains below the 20th percentile. Length is measured in months, and dryness is the average number of percentage points by which soil moisture drops below the 20th percentile;
6. Default agriculture sector weight overall water risk, identifying areas with higher exposure to water-related risks for the agricultural sectors. This is an aggregate risk score calculated combining all indicator as weighted average[16].

Variables #1–5 are taken not as raw values but in terms of indicator scores, classified in 5 intervals: Low (from 0 to 1), Low to medium (from 1 to 2), Medium to high (from 2 to 3), High (from 3 to 4) and Extremely high (from 4 to 5)[17].

The last class of variables includes national-level and time varying data, describing the socio-economic structure, poverty conditions and institutional quality of each country.

With respect to the institutional quality, we include data from two sources. The first is the Polity Database (Center for Systemic Peace)[18] which provides an index (PolityIV) ranging from -10 (strongly autocratic) to 10 (strongly democratic) for all African countries. This is computed by subtracting the "autocratic" score from the "democratic" score and the range of the resulting unified scale is ±10 (see Table A.7 for further details).

13: https://www.wri.org/resources/data-sets/aqueduct-global-maps-21-data. Collection 5.1 MCD12Q1 land cover type data.
14: Total blue water approximates natural river discharge and does not account for withdrawals or consumptive use. Available blue water is an estimate of surface water availability minus upstream consumptive use.
15: The means of total blue water for each of the 12 months of the year were calculated, and the variances estimated between the mean monthly values.
16: The score for overall water risk is the sum of all individual indicators times their weights divided by the sum of all the weights, rescaled to extend through the full range of values (0–5). The weight applied to each indicator is based on its level of importance and relevance in the specific agricultural sector.
17: See Table A.6 for further details.
18: http://www.systemicpeace.org/polity/polity4.htm

Another source on institutional quality is the PRS database[19], providing more detailed information in terms of Political Risk Rating and from which we include 10 weighted variables covering political and social attributes: Government stability; Socio-economic conditions; Investment profile; Corruption; Military in politics; Religious tensions; Law and order; Ethnic tensions; Democratic accountability; Bureaucracy Quality (see Table A.8 for further details). In general terms, if the points awarded are less than 50% of the total, that component can be considered as very high risk. If the points are in the 50–60% range it is high risk, in the 60%–70% range moderate risk, in the 70–80% range low risk and in the 80–100% range very low risk. In addition, we have also calculated an overall index as average among all the sub-components accounted for. Accordingly:

$$\begin{aligned} PRS = [&(Bureaucracy\ Quality/4*6) + Corruption\ + Democratic\ accountability\ +\ Ethnic\ tensions \\ &+\ Law\ and\ order\ + Military\ in\ politics\ + Religious\ tensions \\ &+ (Government\ stability/12*6) + (Socio-economic\ conditions\ /12*6) \\ &+ (Investment\ profile/12*6)]/10 \end{aligned}$$

In order to take into account information on the national poverty conditions, we include four poverty indicators. The first two are derived from the World Bank classification of countries by income, while the two further variables are based on the median level of the adjusted net national income per capita (constant 2010 USD) [20]. In particular, we consider:

1. a dummy variable equal to 1 for all African countries classified as low-income economies, which are those with a Gross national income (GNI) per capita, calculated using the World Bank Atlas method, of 1,005 USD or less in 2016 (as in Bosetti et al., 2018);
2. a categorical variable equal to 1 for low-income economies (as in the previous case), equal to 2 for countries classified as lower middle-income economies (which are those with a GNI per capita between 1,006 and 3,955 USD) and 0 otherwise;
3. a dummy equal to 1 if the country is below the 60 per cent of median income with respect to the overall African continent (in line with the European Union poverty definition[21]);
4. a dummy built as in the previous case but with a poverty 'threshold' set to half of the median (according to the poverty rate definition from OECD[22]).

Additional country level economic variables included are:

1. Agriculture value added as % of GDP (World Bank);
2. Fuel exports as % of merchandise exports (World Bank);
3. Ores and metals exports as % of merchandise exports (World Bank);
4. Foreign direct investment, net inflows (% of GDP)[23].

The last country level information considered come from the CIA factbook[24] and is related to the colonial history, considering the year of independence and dummy variables accounting for which

19: https://www.prsgroup.com/about-us/our-two-methodologies/icrg.
20: In these cases, a country has been classified as poor if it is below the threshold for most of the time periods considered (1990–2016).
21: http://www.poverty.ac.uk/definitions-poverty/income-threshold-approach
22: https://data.oecd.org/inequality/poverty-rate.htm
23: Foreign direct investment are the net inflows of investment to acquire a lasting management interest (10 percent or more of voting stock) in an enterprise operating in an economy other than that of the investor. It is the sum of equity capital, reinvestment of earnings, other long-term capital, and short-term capital as shown in the balance of payments.
24: https://www.cia.gov/library/publications/resources/the-world-factbook/

country the independence was gained from, e.g. France, Portugal, UK, Belgium, Spain, Italy, Others (see Table A.9 for a complete list of variables and sources).

Additional controls and corrections applied to the dataset are for the presence of outlier observations. In particular, we exclude from the grid all those cells geographically located on the coastline, for which climate data were not available.

Furthermore, for three variables from the Aqueduct Water Risk Atlas, we correct the values for those cells with a negative value (the index was supposed to range from 0 to 5). In particular, for the Drought Severity scores index from Aqueduct Water Risk (DRO), there were two cells for which the index was outside of the acceptable range and, accordingly, the values were substituted with the average value from the surrounding eights cells. For the Inter-annual Variability and Seasonal variability (respectively SV and WSV) in some cases (253) the index values were negative, and we corrected them with 0.

Further descriptions of the dataset and a summary of the date are given in the Annex to this paper.

4. Methodology

The final database results from the association of all the aforementioned variables to each grid cell for each year. The grid we rely on, derived from the GDP and population data, is created with the QGIS software and divides the African continent in georeferenced cells of approximately 110×110 km.

Firstly, starting from the UPPSALA Database, we select conflicts occurred in Africa over the period 1990 to 2016 and associate each conflict and the related number of deaths to the grid cell where the event took place[25]. In this respect, it has to be noted that the GED dataset reports three different estimations for the number of deaths for each conflict: the variable *best* represents the most likely estimate of total fatalities resulting from the event and is defined as the sum of the deaths sustained by both sides involved in the conflict and dead civilians; while the two variables *low* and *high* represent, respectively, the lowest and highest reliable estimates of total fatalities. Then, we calculate the number of conflicts (*nc*) that occurred in each grid cell and the different estimates for the number of deaths (*nd*), as the sum by cell of the variables *best*, or *low* or *high*[26]. The conflict dummy variable (*cd*), equal to 1 for all grid cells where at least one conflict has been registered and 0 otherwise, has also been added together with the variable representing the year.

Similarly, we link the 13 raster files representing the climate information to each centroid of the grid cell.

Then, we merge (by grid cell and year) the conflict and climate to the GDP and population information, as well as to the georeferenced time invariant data (the dummy variables for resources, forest, rural and the water stress indices) and the country level time series variables (institutions and socioeconomic data).

These steps must be replicated for all the 27 years included into the database (1990–2016), thus at the end of this procedure, the resulting 27 data files, homogeneous in terms of structure and

25: We used the WGS84 reference system that roughly corresponding to a geographical representation of latitude and longitude (it comprises a standard coordinate system for the Earth, a standard spheroidal reference surface for raw altitude data and a gravitational equipotential surface that defines the nominal sea level).

26: Because the variable counting the number of conflicts has been calculated as the sum of the conflicts per cell, for those cells with no conflicts, we correct the Null values with 0.

variables included, have been combined in a single balanced panel dataset (3,402 grid cells and 27 years).

In addition, since for some conflicts (4,972) the number of fatalities reported as the best estimate was 0, we build a fourth variable counting the number of deaths (*deaths_nz*) that assumes a positive non-zero value for each conflict accounted for. Accordingly, this variable is equal to best if best has a non-zero value and to the lowest (non-zero) value between low and high otherwise[27].

Furthermore, we calculate three indicators to account for the distribution and concentration of the national economic resources among cells. The first is a Gini index based on GDP, calculated for each grid cell i with respect to the other cells from the same country c in each year t *(inequality of a distribution).*

Secondly, we introduced the variable, GDP_*sh*, that represents for each year t the share of the grid-cell GDP with respect to the national GDP:

$$GDP\_sh = \frac{GDP_{i,c,t}}{GDP_{c,t}} \quad (1)$$

The third variable is the natural logarithm of the ratio between the cell GDP and the average GDP at the country level ($GDP_{\bar{c},t}$):

$$GDP_{ln} = \ln\left(\frac{GDP_{i,c,t}}{GDP_{\bar{c},t}}\right) \quad (2)$$

The longitudinal nature of the database would allow the temporal dependence to be controlled, but we will also need to account for the presence of spatial dependence among the observations. Hence, considering four spatial weighting matrices based on the inverse distance function (150 km, 250 km, 500 km and 1000 km), the next step will be to calculate the Moran I test, which measures the spatial autocorrelation between each grid cell and the nearby locations based on different spatial weight matrices. For each distance threshold, the Moran I test will applied for both dependent and independent variables, in particular:

- conflict dummy, number of conflicts and number of deaths;
- temperature, precipitation and SPI-12 climate variables;
- standard deviation of temperature and precipitation with respect to the previous 5 years;
- GDP, GDP per capita and the variation in GDP per capita between t and t-1.

Based on the results (using Geoda and R software), the spatial matrix will be used to estimate spatial panel regression models and to build a new set of spatially-lagged (dependent and independent) variables, calculated considering for each original variable the appropriate distance threshold beyond which the spatial dependence among grid cells is no longer significant.

The next Section provides a descriptive analysis of the dataset and some maps illustrating the African continent with respect to the main variables included into the CACAO database.

27: In almost all the cases the best value is substituted by the corresponding high estimates of deaths, and only in 2 (for which the low estimate was positive while the value of the corresponding high and best variables was 0) by the low estimate.

5. Descriptive analysis and maps

A summary of the data is provided in the Annex (see Tables A.1 and A.2). Over the dataset there are 91,854 observations for the cells over time and Table 2 indicates that overall about 6.3 percent of them are characterised by the presence of a conflict.

Table 2: Conflict dummy (cd)

cd	Freq.	Percent	Cum.
0	86,072	93.71	93.71
1	5,782	6.29	100.00
Total	91,854	100.00	

5.1 Time series

Figure 1 and Table 3 give the data on the share of cells with at least one conflict over the period 1990 to 2016. The figure shows a discernible increase in the period since 2001. Figure 2 shows the number of conflicts by year where the increase over time is less clear but there is some evidence for a positive trend after 2006. Figure 3 on the number of deaths over time shows no clear trend. Figures 4 plot average temperature and precipitation over time (daily average and annual SPI), both showing a positive trend that is significant at the 99% level[28].

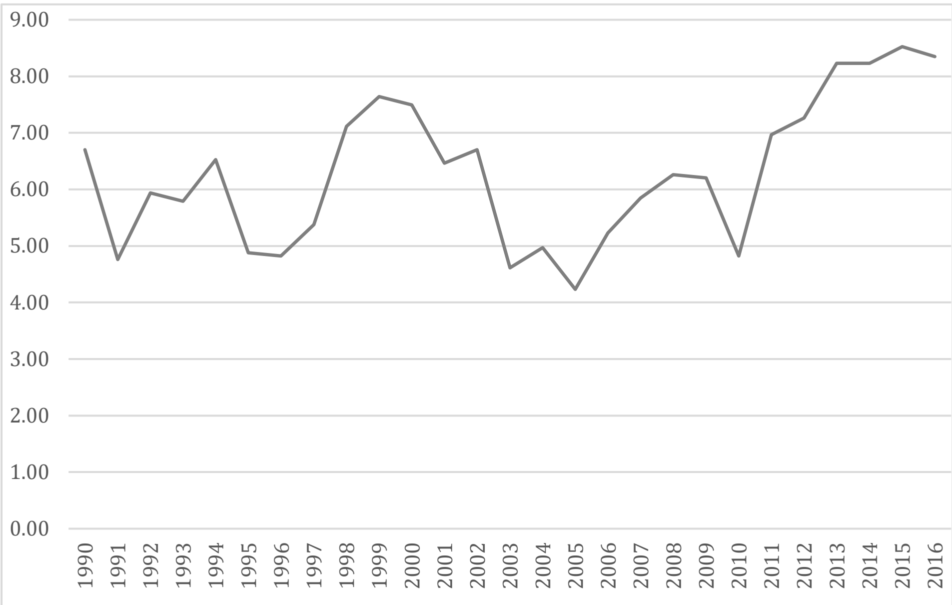


Figure 1: Share (%) of grid cells with registered conflicts

28: Figures of the data on conflicts and deaths by country over time are in the Annex (Figures A.1 and A.2). See also Table A.3 for further statistics by year.

Table 3: Conflict dummy by year: share (%) of grid cells with and without registered conflicts

	No conflict	*At least 1 conflict*
cd	0	1
1990	93.30	6.70
1991	95.24	4.76
1992	94.06	5.94
1993	94.21	5.79
1994	93.47	6.53
1995	95.12	4.88
1996	95.18	4.82
1997	94.62	5.38
1998	92.89	7.11
1999	92.36	7.64
2000	92.50	7.50
2001	93.53	6.47
2002	93.30	6.70
2003	95.39	4.61
2004	95.03	4.97
2005	95.77	4.23
2006	94.77	5.23
2007	94.15	5.85
2008	93.74	6.26
2009	93.80	6.20
2010	95.18	4.82
2011	93.03	6.97
2012	92.74	7.26
2013	91.77	8.23
2014	91.77	8.23
2015	91.48	8.52
2016	91.65	8.35

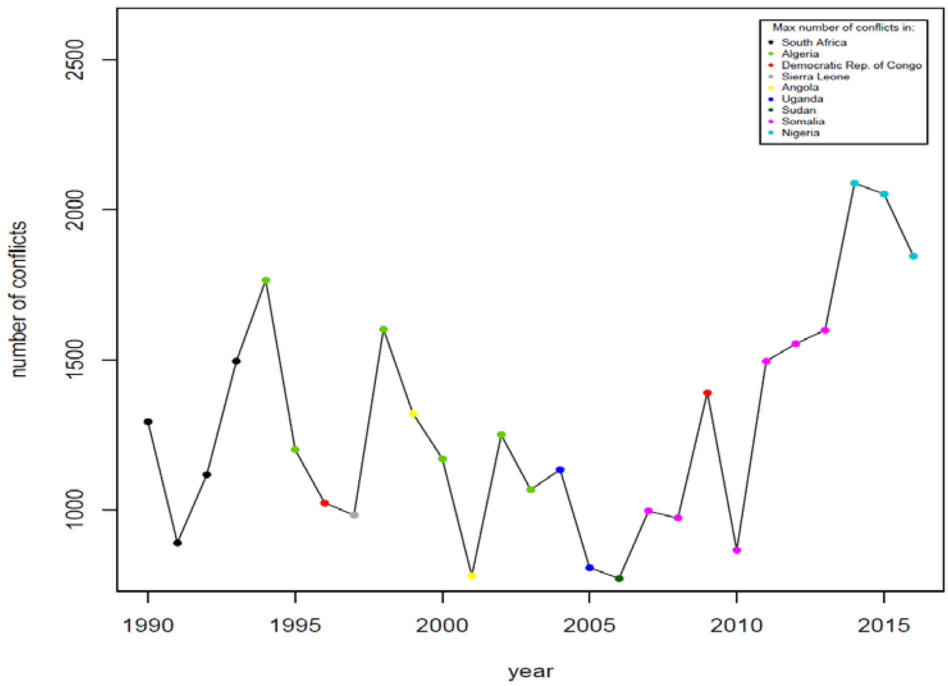


Figure 2: Number of conflicts by year (peak-country)

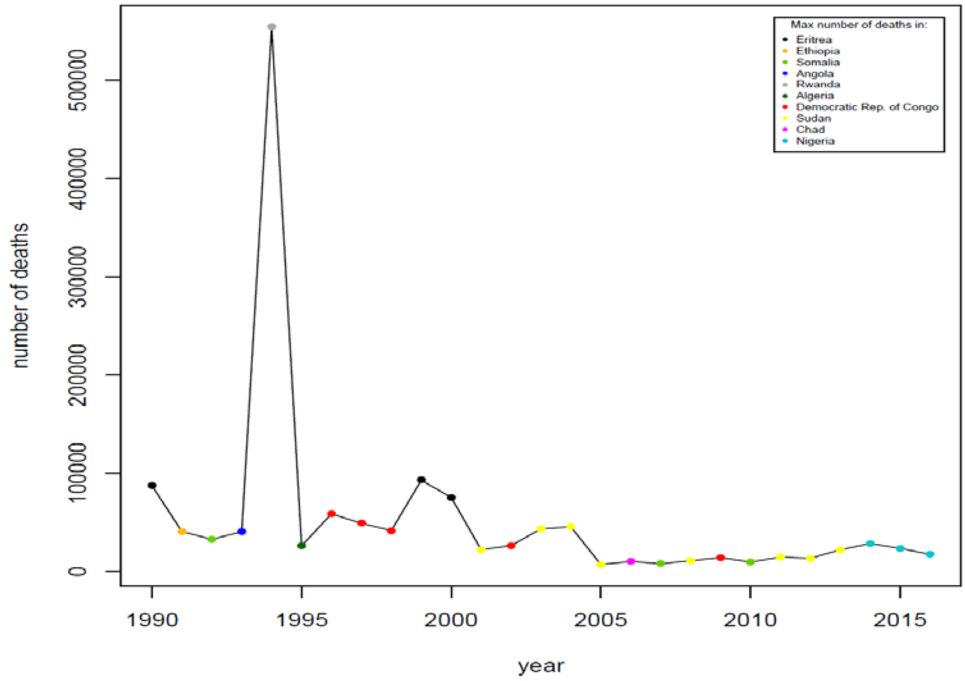


Figure 3: Number of deaths by year (peak-country)

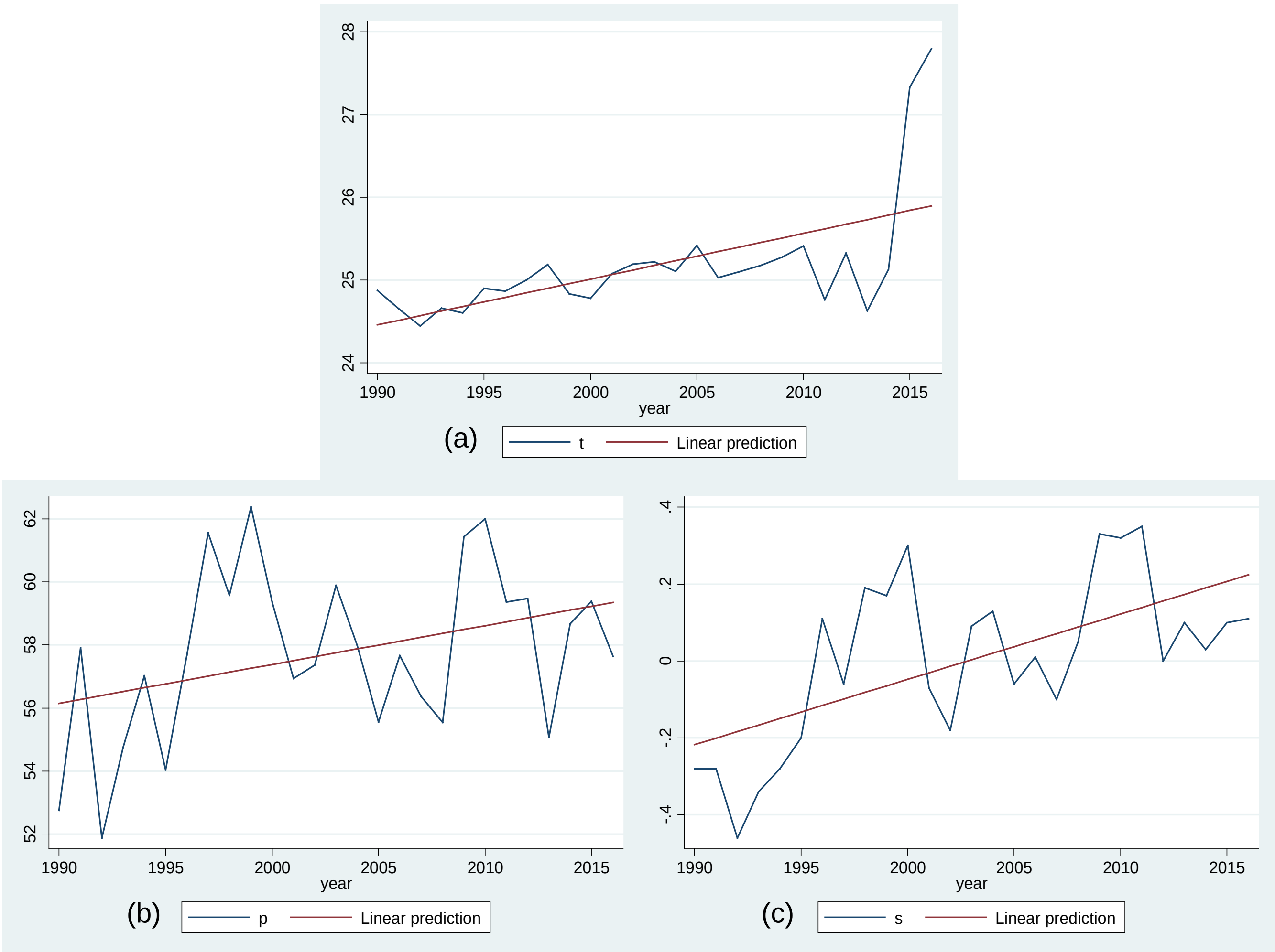


Figure 4: Climate, averaged by year. (a) *Temperature (ºC),*
(b) *Precipitation (mm/day),* (c) *Precipitation (SPI-12)*

5.2 Cross section by country

This sub-section looks at the data at the cross section of data by country (summarized in Tables A.4 and A.5, as well as in Figures 5 and 6). The highest number of conflicts are found to be in Algeria, the DCR, Nigeria, Somalia and Sudan, while the greatest number of deaths were in Rwanda, Sudan, Eritrea, DCR and Ethiopia.

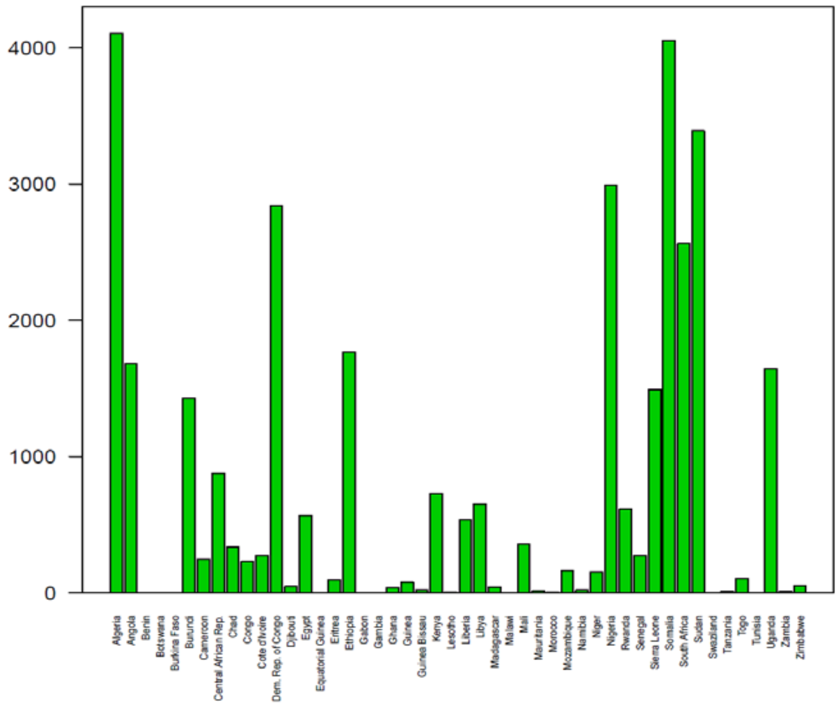


Figure 5: Total number of conflicts by country

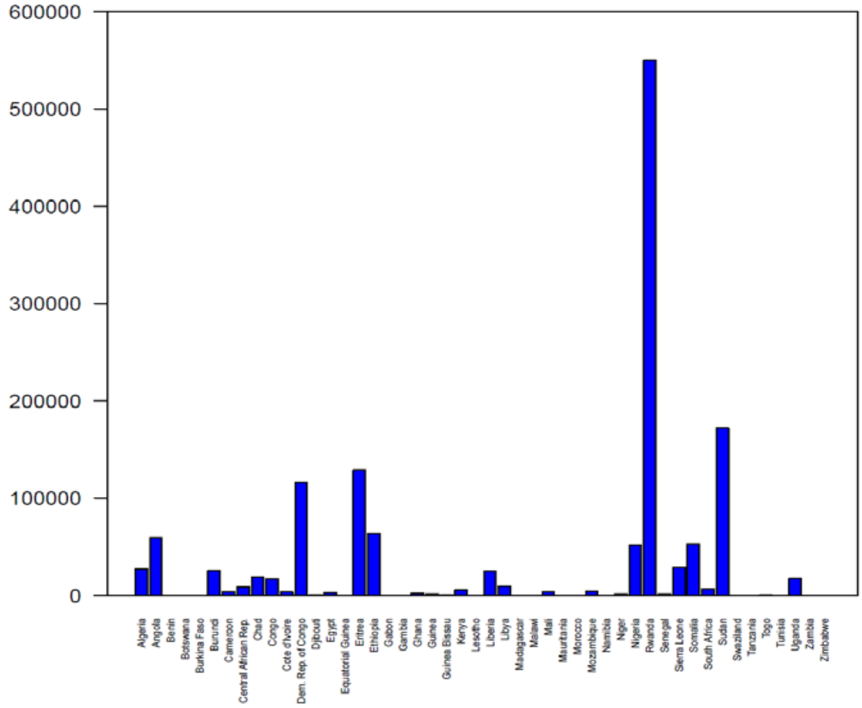


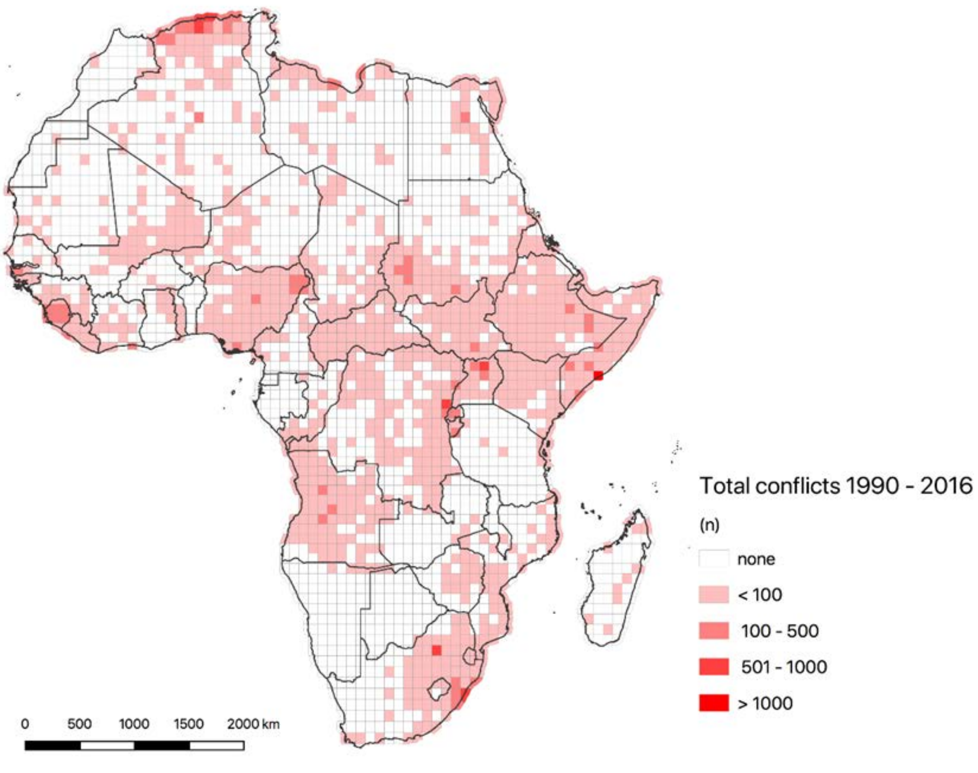
Figure 6: Total number of deaths by country

5.3 Maps

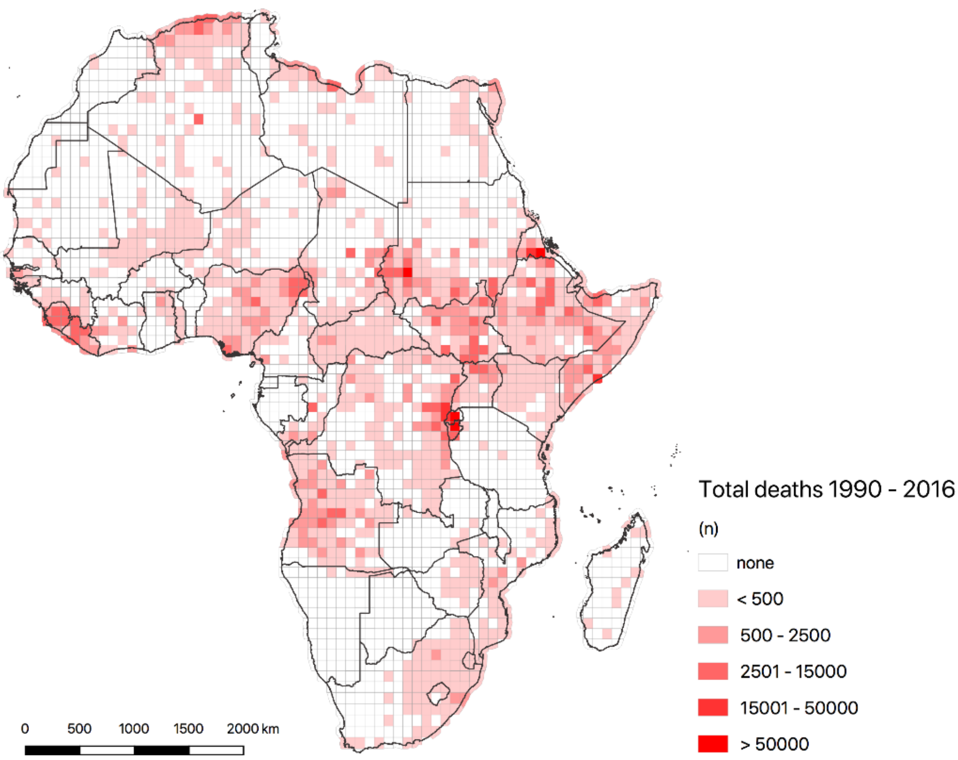
This sub-section overlays the data on conflicts by geo-referenced cell across maps of Africa. Map 1 reports total conflicts over the period 1990–2016. There is a concentration in the central belt of the continent, as well as pockets in the North and South East. Map 2 does the same for number of deaths, which tells a similar picture. Map 3 overlays the number of conflicts with energy and mineral resources and Map 4 includes water resources as well. There is a notable overlay of the conflict zones with the concentrations of energy and mineral resources, while that with water resources is less clear.

Map 5 shows where the temperatures are highest on the continent and Map 6 shows where the temperature increases have been greatest in the last three decades. The highest temperatures are, not surprisingly in the Sahel region but the increases over the period have not been highest there –rather they have been in parts of the North West and the South West. The direct link to conflicts therefore appears weak. Map 7, however, which lays out the change in the standard deviation of temperature, points to a greater increase in the pockets in the North and South, where conflicts have also increased. Maps 8–10 lay out precipitation (Map 8), changes in precipitation (Map 9) and changes in the standard deviation of precipitation (Map 10). Precipitation has increased notably in the central belt and decreased notably in the south east, both regions where conflicts have also risen. The standard deviation of precipitation has risen in pockets in central belt as well.

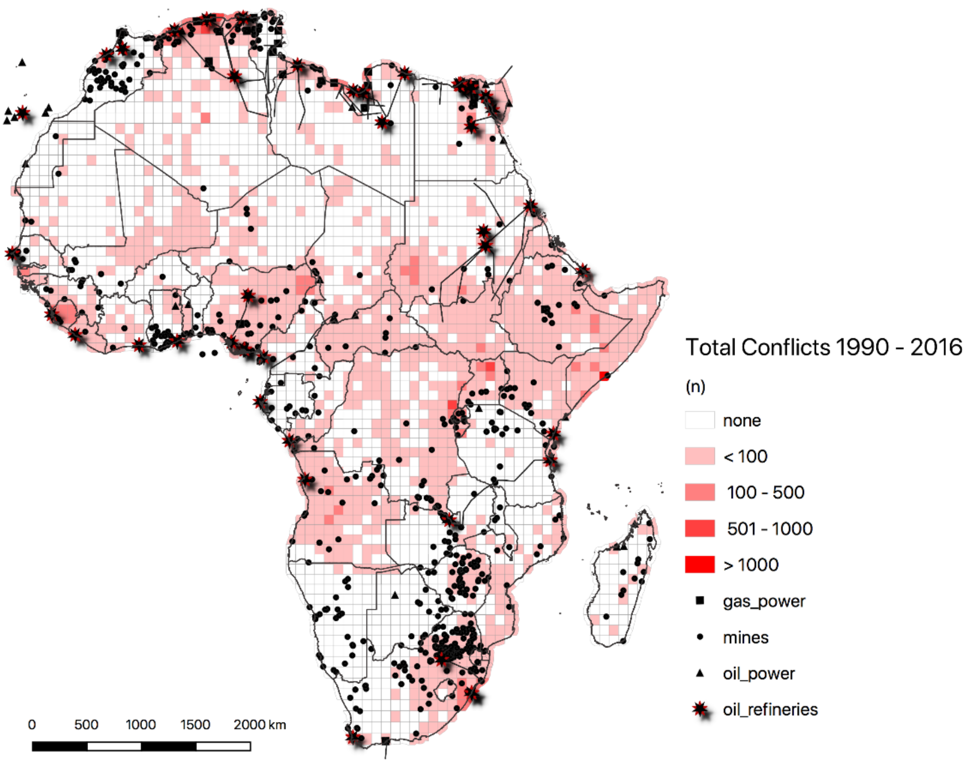
Maps 11–12 plot GDP and its changes, and Maps 13–14 do the same for population. In terms of changes in GDP patterns are hard to discern, and probably significantly influenced by population movements at the cell level. Population moves also have complex relative patterns that need further analysis.



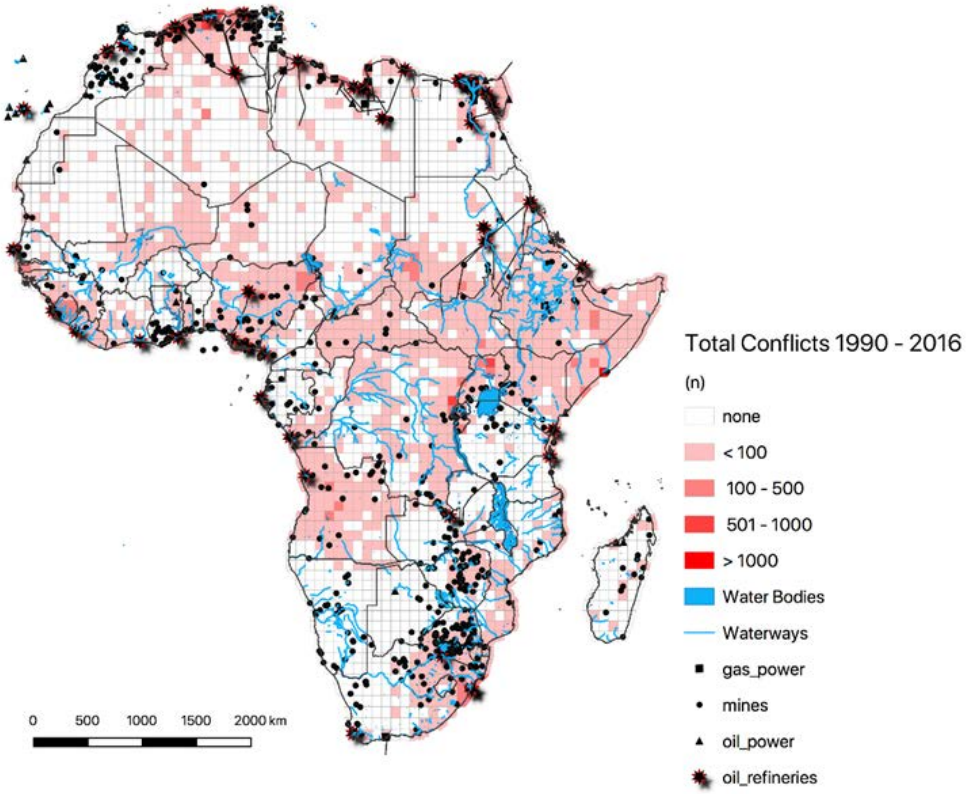
Map 1: Conflicts: total number of conflicts (1990–2016)



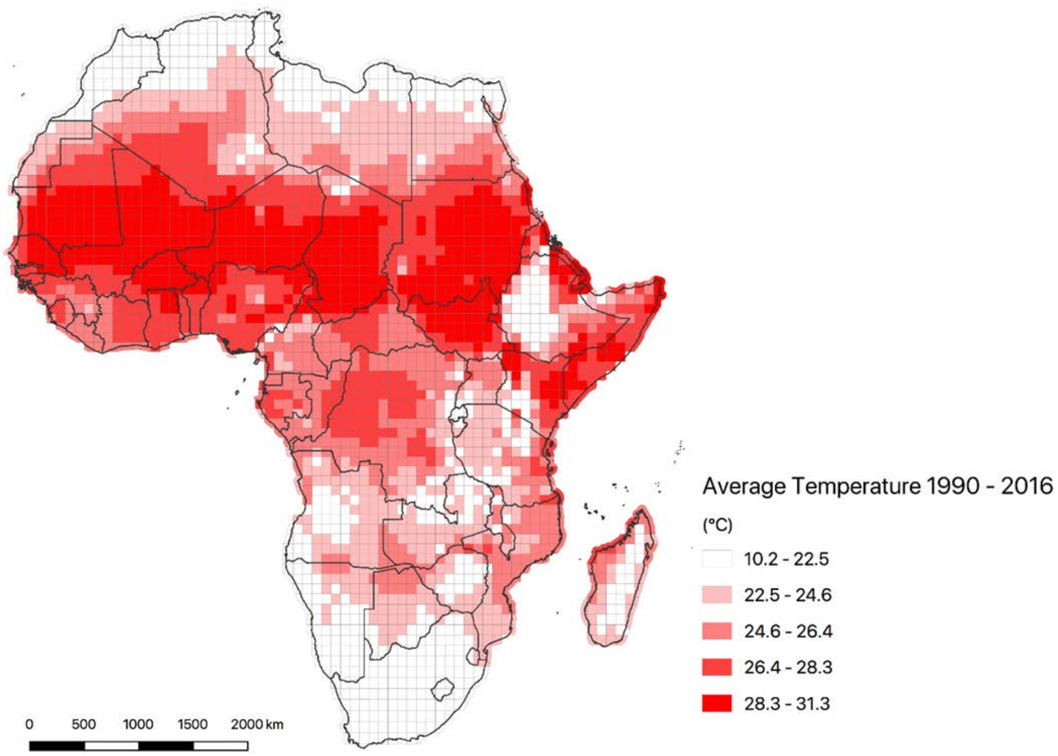
Maps 2: Conflicts: total number of deaths (1990–2016)



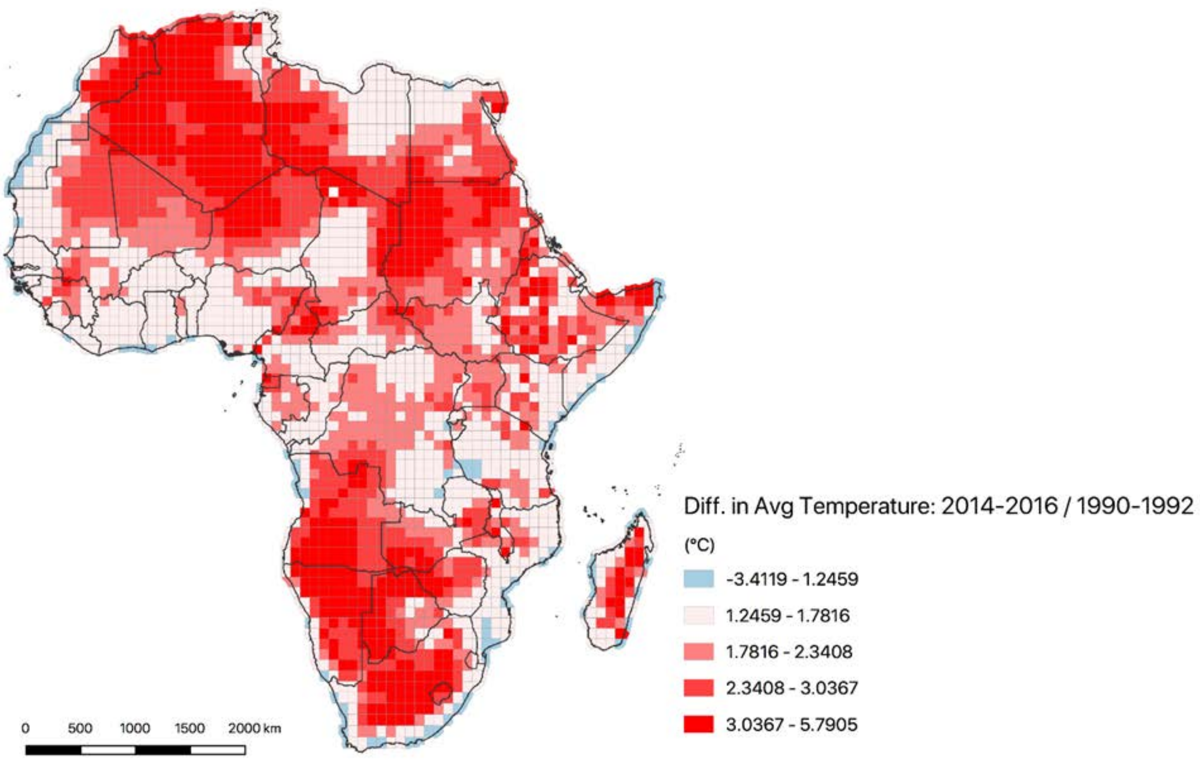
Map 3: Conflicts: total number of conflicts (1990–2016) resources



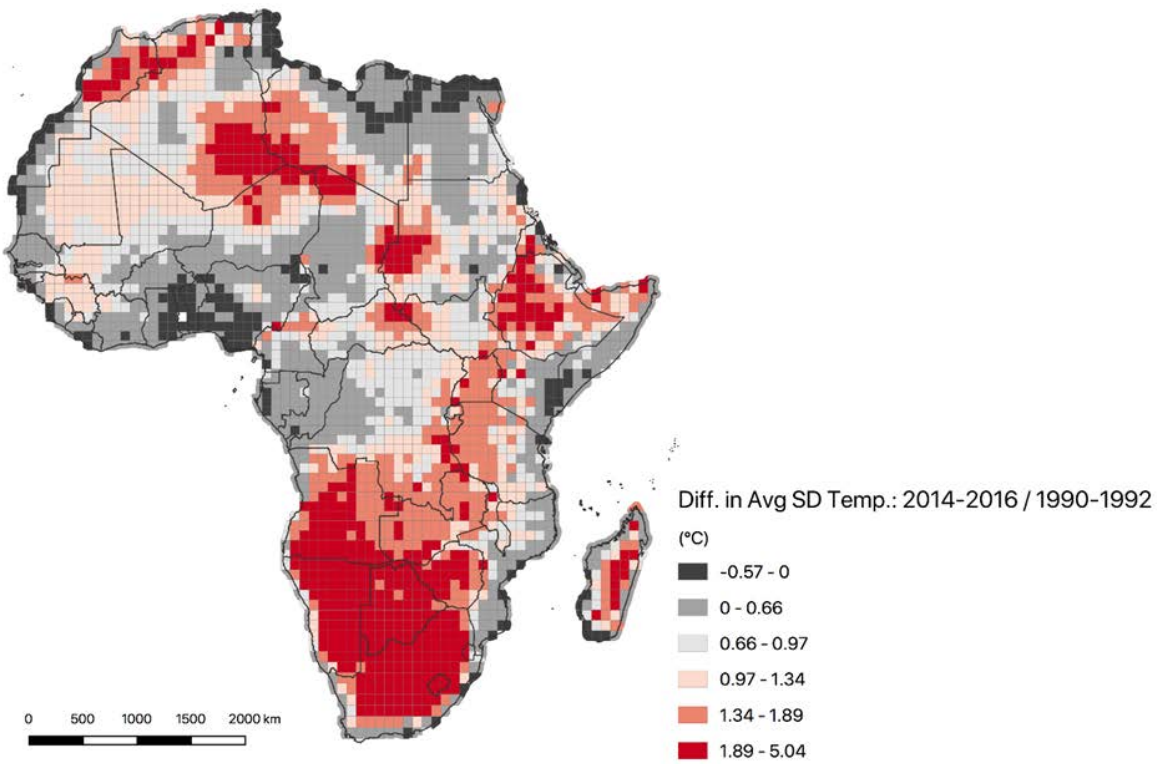
Map 4: Conflicts: total number of conflicts (1990–2016), resources and water



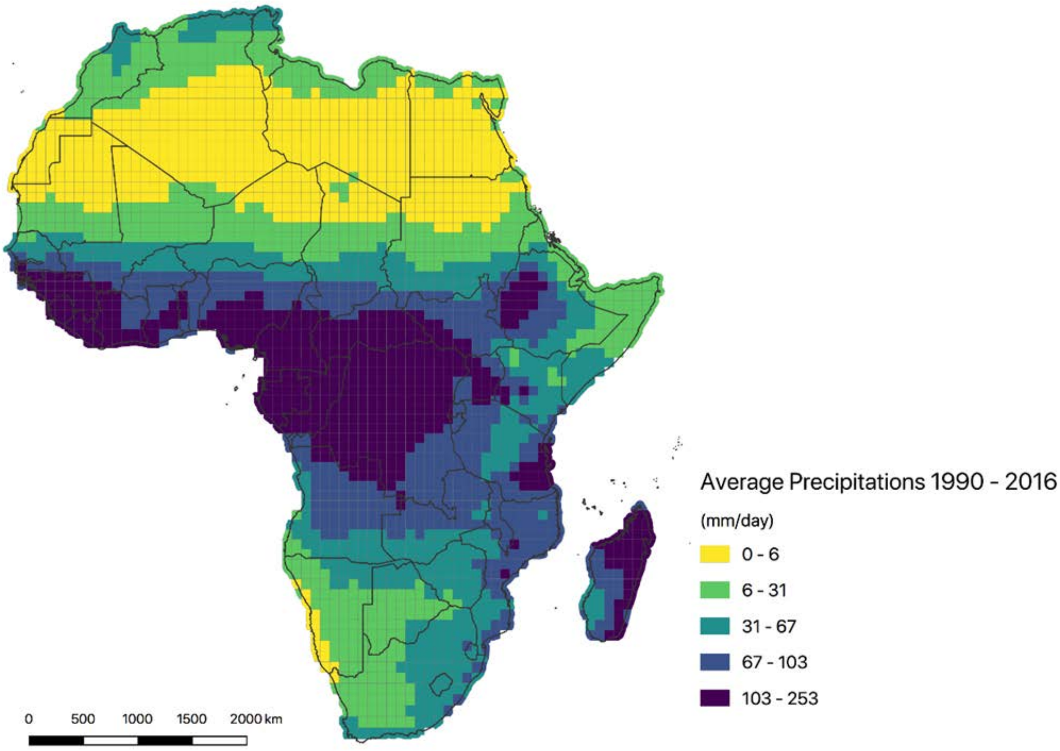
Map 5: Temperature: average temperature (1990–2016)



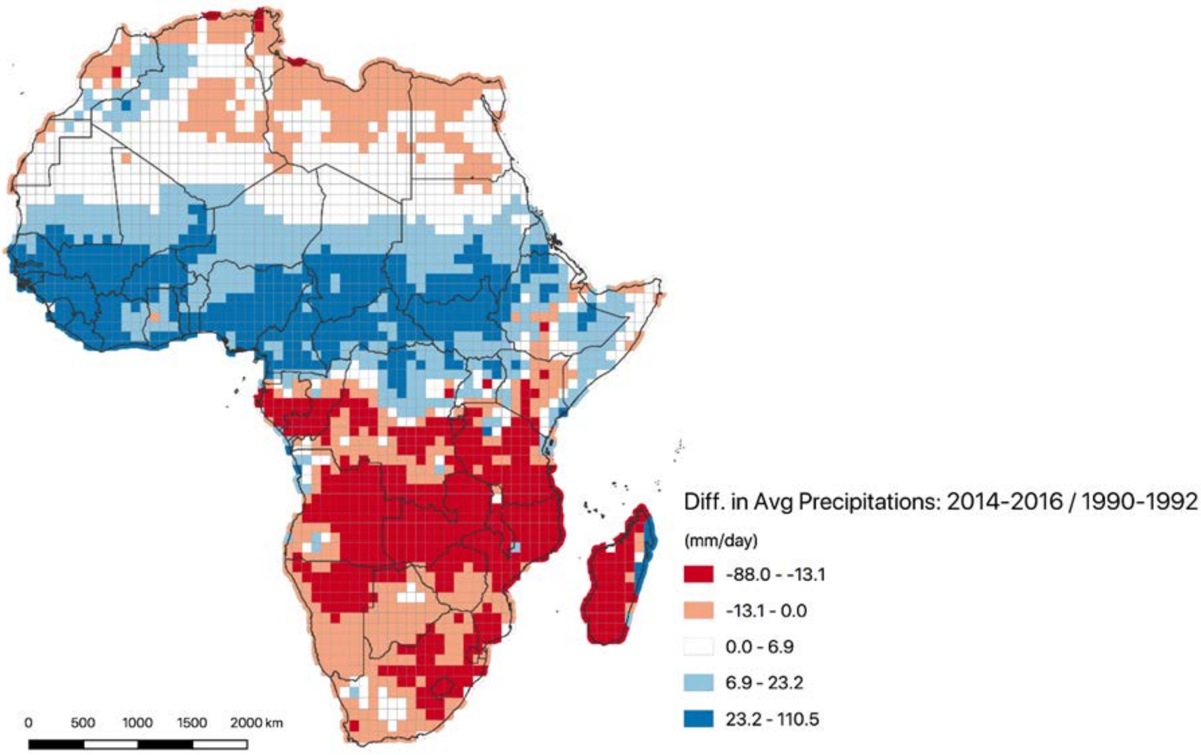
Map 6: Temperature: change in average temperature (1990–2016)



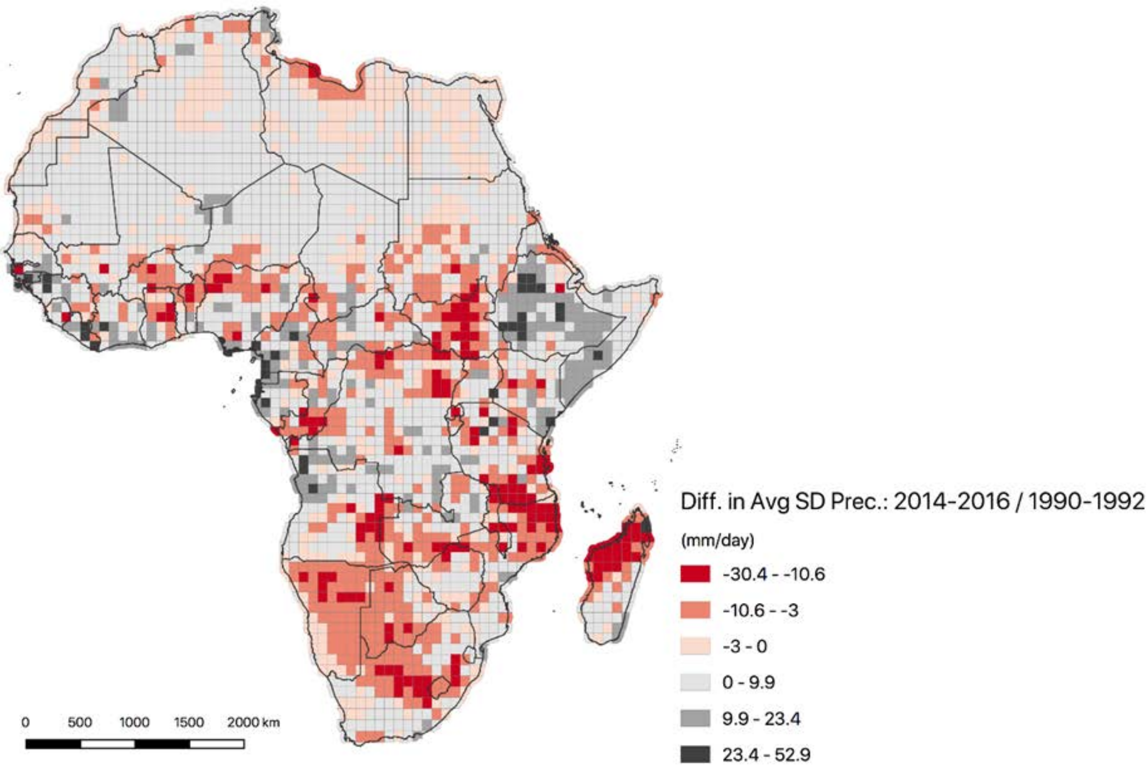
Map 7: Temperature: change in average standard deviation in temperature (1990–2016)



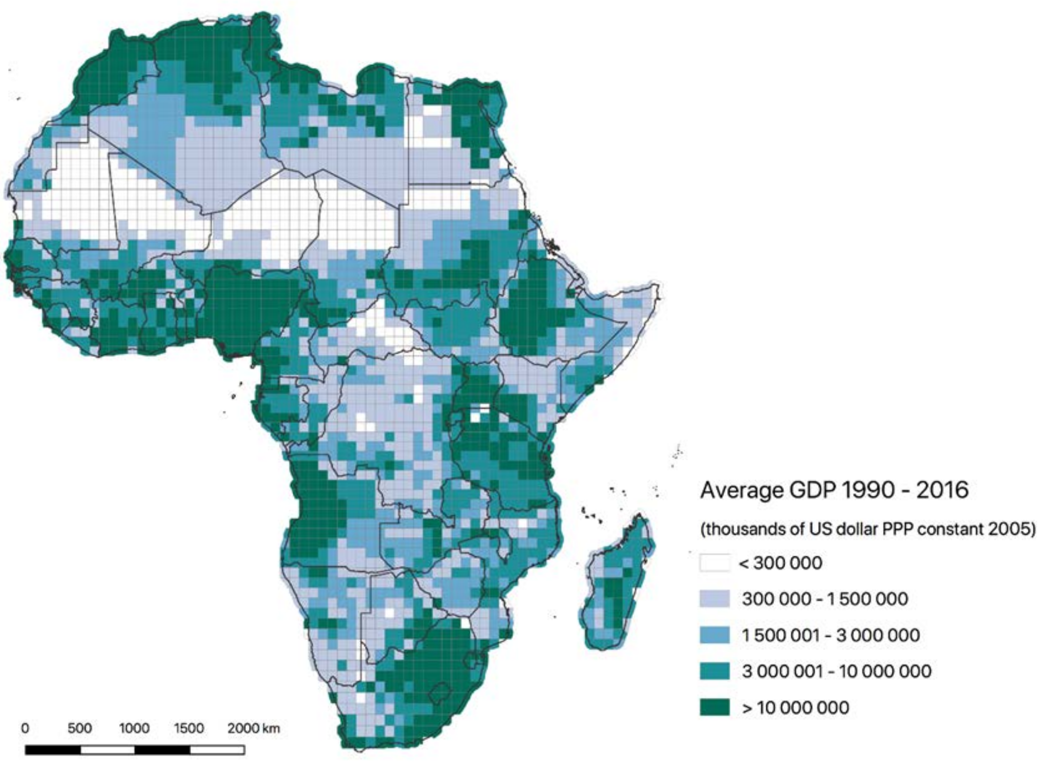
Map 8: Precipitation: average precipitation (1990–2016)



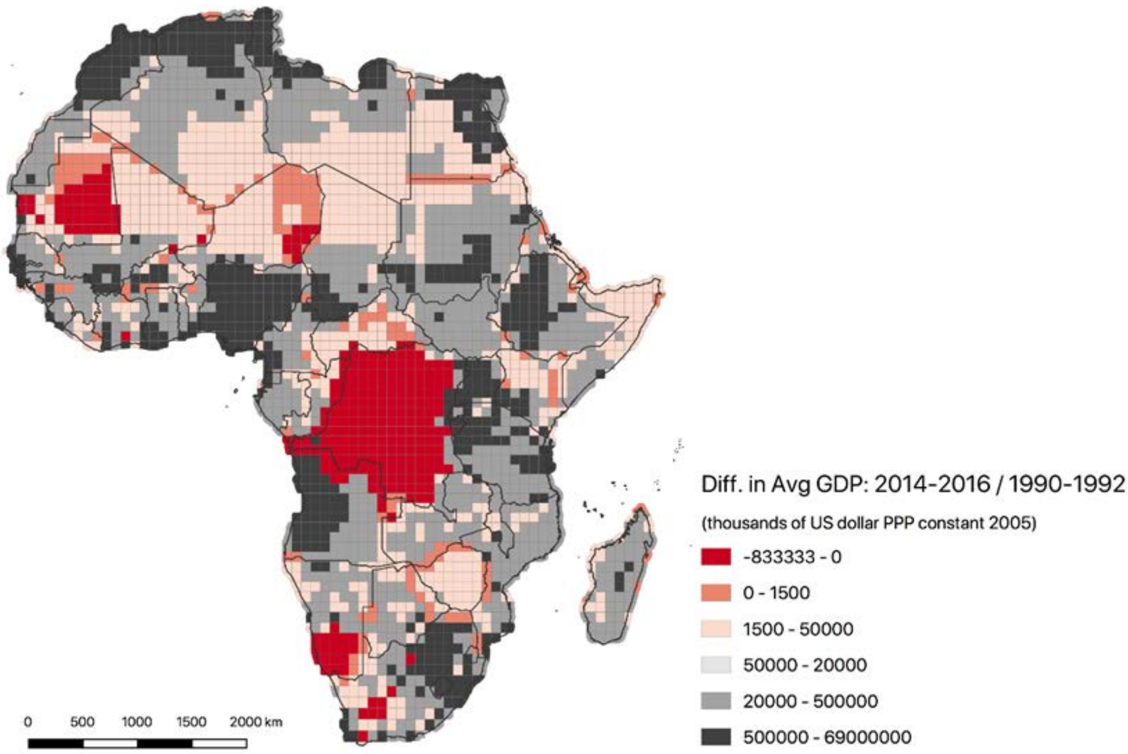
Map 9: Precipitation: change in average precipitation (1990–2016)



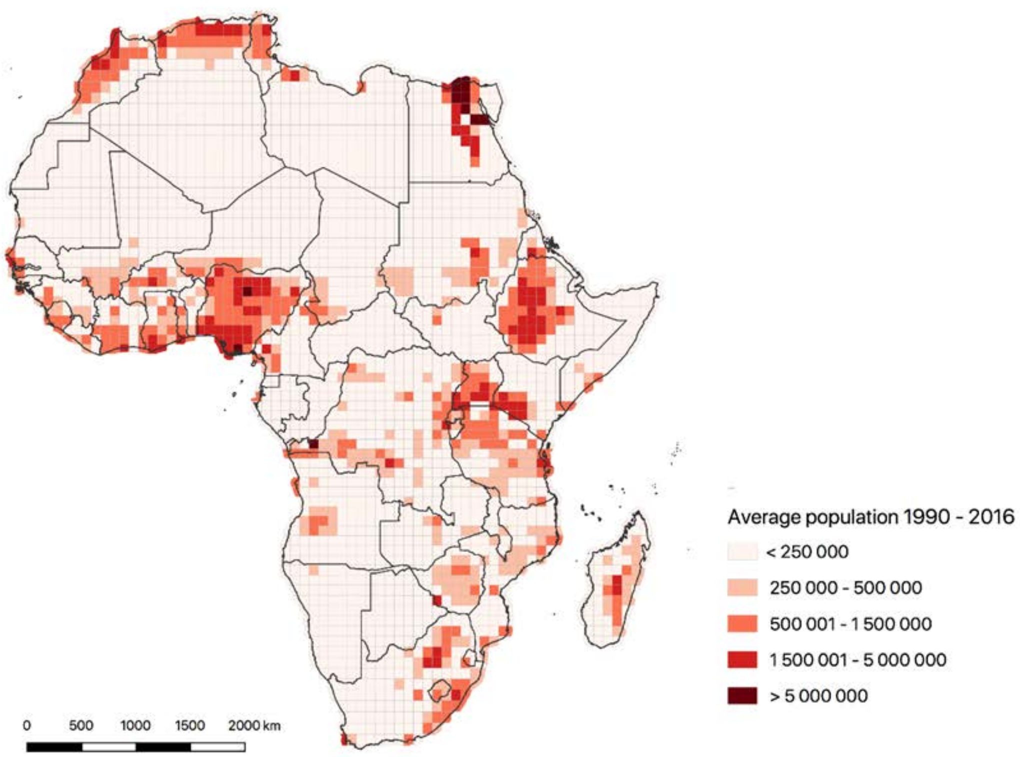
Map 10: Precipitation: change in average standard deviation in precipitation (1990–2016)



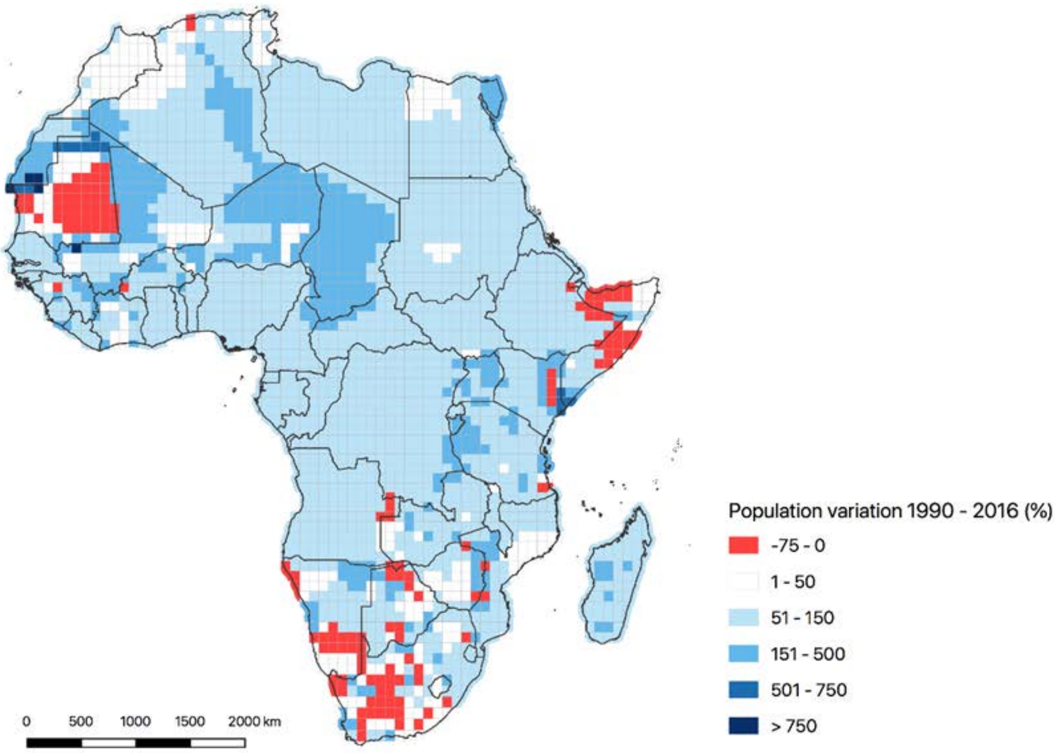
Map 11: GDP: average GDP (1990–2016)



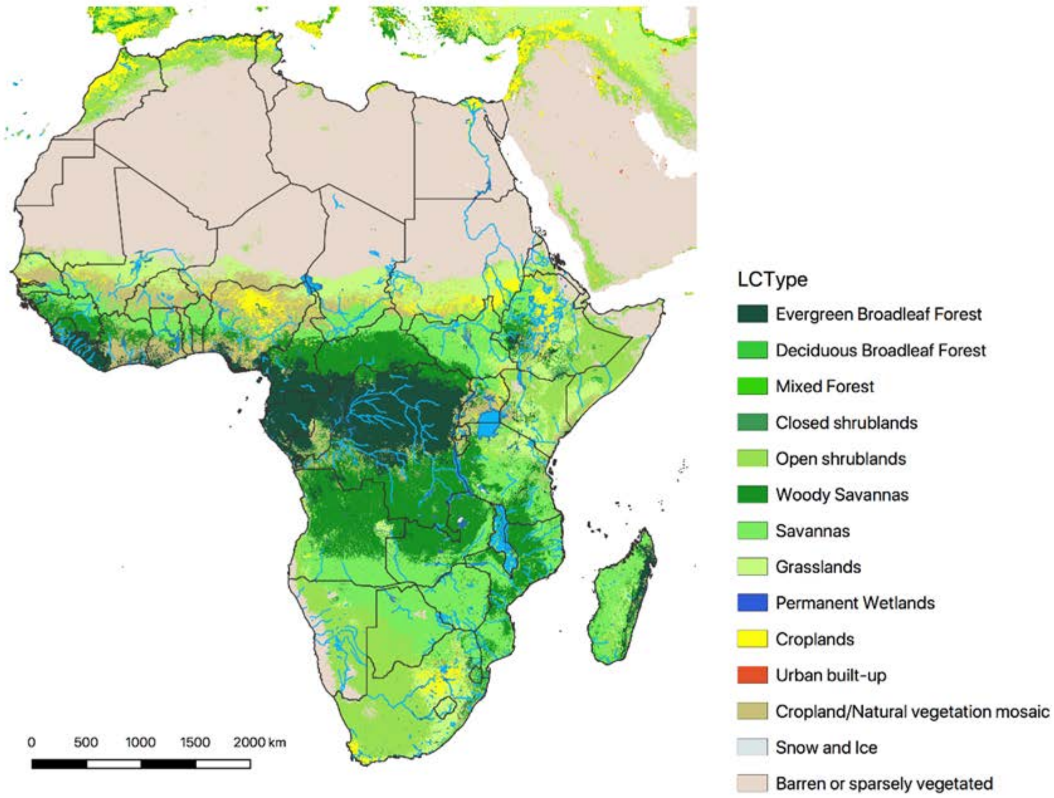
Map 13: Population: average population (1990–2016)



Map 12: GDP: change in average GDP (1990–2016)



Map 14: Population: change in average population (1990–2016)



Map 15: Land cover

6. Discussion and conclusion

This paper represents an attempt to develop a methodological approach to build a database to comprehensively map and analyse African countries through a geo-referenced representation of the climate and socio-economic characteristics starting from the conflicts occurred in almost three decades from 1990 to 2016 in a local rather than a country level analysis (110×110 km grid cells).

During this period, the African continent has been characterized by a high number of conflicts, from the last years of Apartheid in South Africa and the Rwandan Civil War of the '90s to the Arab Spring of the recent years. The most violent region has been, on average, the Horn of Africa indeed in terms of conflict magnitude, the Eastern part of Africa has registered a very large number of victims over the analysed period, followed by South-East Africa and Western Sub-Saharan areas (Maps 1 and 2).

As for climate variables, we take data on temperature, precipitation and deviations from long-term normal rainfall (SPI-12), not only in level but also accounting for the variations with respect to the previous years. Most of Africa has experienced a sharp increase of temperature (Maps 5-6), while precipitations mainly rose in the area under the Sahara Desert and decreased in northern and (especially) southern Africa (Maps 8–9).

In this context, considering the specific location of each registered conflict, the first aim is to analyse the role played by climate change in affecting the conflicts dynamics, the risk of onset and magnitude, both in terms of number of registered events and fatalities. At the same time, as largely recognised in literature and partly summarised in the presented maps, there are several other aspects that could aggravate (or offset) the local conditions, eventually degenerating in armed conflicts. Hence, the third class of variables collected at the grid-cell level and time-varying includes GDP and population. Not surprisingly, most of the disputes have occurred in populated places developed near water basins, while very few conflicts arise in desertic areas. Furthermore, we have also collected geo-referenced information on geography, land use, water stress, natural resources and infrastructure availability (mostly taken from remote sensing data) and country level socio-economic data (as for instance income inequality, institutional quality, colonial history and the role of agriculture and exports of fuels and minerals within the national economic structure). Conflicts seem to mainly erupt in populated areas that are also rich of natural resources, as illustrated in Map 3, but further analysis is needed in order to disentangle the role of the different drivers and, considering the georeferenced and time-horizon dimension of the panel, to account for the spatial and temporal dependence, highlighting direct as well as indirect impacts. Considering the presence of spatial dimension and dependence among observations, also the impact of climate (and climate variations) and other geographical and socio-economic covariates registered in the neighbouring cells could be disentangled, as for example in terms of resource curse hypothesis. In addition, considering the temporal dimension of the panel, further discussion could be provided in terms of conflict traps, given that it is resealable to consider quite relevant what has happened in the past.

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Annex A

Table A.1: Summary – georeferenced variables

	Variable	Obs	Mean	Std. Dev.	Min	Max
id grid-cell	id_g	91854	1701.50	982.08	1.00	3402.00
year	year	91854	2003	7.79	1990	2016
Georeferenced time-variant						
Conflicts	# deaths_best	91854	12.85	1294.30	0.00	372685.00
	# deaths_low	91854	8.89	418.25	0.00	72126.00
	# deaths_high	91854	20.31	2160.01	0.00	636500.00
	# deaths_nz	91854	15.43	1342.62	0.00	384744.00
	# conflicts	91854	0.38	3.81	0.00	248.00
	Dummy conflict	91854	0.06	0.24	0.00	1.00
Climate	Precipitation	91854	57.75	52.12	0.00	399.96
	SPI-12	91854	0.00	0.97	-3.72	3.72
	Temperature	91854	25.18	3.55	6.63	34.28
GDP-POP	GDP	91854	601973.10	3023916.00	0.29	120000000.00
	POP	91854	256176.20	716349.00	0.97	27000000.00
	GDP per capita	91854	300986.50	1511958.00	0.15	60000000.00
	GDP_sh (eq. 1)	91854	1.41	4.08	0.00	69.91
	GDP_ln (eq. 2)	91854	-1.62	2.26	-13.00	4.20
	GINI index	91854	0.71	0.12	0.33	0.89
Georeferenced time-invariant						
Resources	Dummy_resources	91854	0.23	0.42	0.00	1.00
	Dummy_forest	91854	0.08	0.27	0.00	1.00
	Dummy_rural	91854	0.11	0.31	0.00	1.00
Water Stress	Baseline Water stress	91854	1.59	2.06	0.00	5.00
	Drought	91854	2.45	1.45	0.00	5.00
	Flood	91854	2.04	1.03	0.00	4.06
	Seasonal var.	91854	2.38	1.38	0.00	5.00
	Inter-annual var.	91854	2.22	1.37	0.00	5.00
	Agr. Water risk	91854	2.33	1.05	0.00	4.89

Table A.2: Summary – country-level variables

	Variable	Obs	Mean	Std. Dev.	Min	Max
Country level time-variant						
	Fuel (% export)	91854	28.69	39.69	0.00	99.66
	Min (% export)	91854	11.52	20.13	0.00	88.81
	Agriculture VA (% GDP)	91854	25.61	16.35	0.89	93.98
	Foreign direct investment	91854	3.27	6.15	-82.89	161.82
Institution	Bureaucracy Quality	91854	1.33	0.83	0.00	4.00
	Corruption	91854	2.17	1.06	0.00	5.40
	Democratic accountability	91854	2.81	1.23	0.00	5.50
	Socio-eco. conditions	91854	3.83	1.81	0.00	10.80
	Ethnic tensions	91854	2.99	1.43	0.00	6.00
	Government stability	91854	7.39	2.44	0.00	11.58
	Investment profile	91854	6.35	2.27	0.00	11.50
	Law and order	91854	2.80	1.24	0.00	6.00
	Military in politics	88504	2.38	1.69	0.00	6.00
	Religious tensions	91854	3.54	1.58	0.00	6.00
	PRS index	91854	2.75	0.89	0.30	5.40
	Polity2 Index	91779	-0.05	5.11	-10.00	9.00
Country level time-invariant						
Poverty	Dummy_PovertyWB	91854	0.43	0.50	0.00	1.00
	[0, 1, 2]	91854	1.12	0.74	0.00	2.00
	Dummy_Poverty06	91854	0.54	0.50	0.00	1.00
	Dummy_Poverty05	91854	0.53	0.50	0.00	1.00
Colonial history	Dummy_France	91854	0.40	0.49	0.00	1.00
	Dummy_Portugal	91854	0.07	0.25	0.00	1.00
	Dummy_UK	91854	0.39	0.49	0.00	1.00
	Dummy_Belgium	91854	0.07	0.26	0.00	1.00
	Dummy_Spain	91854	0.00	0.05	0.00	1.00
	Dummy_Italy	91854	0.04	0.18	0.00	1.00
	Dummy_Other	91854	0.04	0.19	0.00	1.00
	Independence year	91854	1958.25	14.74	1910.00	1993.00

Table A.3: Conflicts, Climate, GDP and population by year

	Total number of conflicts	Total number of deaths	Temperature (mean) ° Celsius	Precipitation (mean) Mm/day	SPI-12 (mean)	GDP (mean)	POP (mean)
1990	1,293	87,499	24.88	52.76	-0.28	365,787	182,372
1991	890	40,664	24.65	57.92	-0.28	371,158	186,996
1992	1,117	32,867	24.44	51.88	-0.46	378,063	192,216
1993	1,494	40,520	24.66	54.75	-0.34	384,371	197,383
1994	1,765	554,443	24.60	57.03	-0.28	392,923	202,660
1995	1,200	26,176	24.90	54.04	-0.20	396,154	206,547
1996	1,023	58,694	24.87	57.68	0.11	412,954	212,148
1997	982	49,046	25.00	61.56	-0.06	430,237	217,733
1998	1,602	41,690	25.19	59.58	0.19	447,686	223,145
1999	1,321	92,996	24.83	62.37	0.17	465,931	229,816
2000	1,170	75,408	24.78	59.34	0.30	477,718	233,916
2001	780	22,191	25.08	56.94	-0.07	501,180	239,762
2002	1,249	26,404	25.19	57.37	-0.18	526,876	245,615
2003	1,067	43,467	25.22	59.89	0.09	554,490	251,758
2004	1,134	45,480	25.10	57.97	0.13	585,846	258,220
2005	807	7,004	25.42	55.56	-0.06	595,519	262,911
2006	771	10,221	25.03	57.67	0.01	624,695	269,392
2007	995	7,882	25.10	56.37	-0.10	656,417	276,533
2008	972	10,946	25.18	55.54	0.05	689,582	283,090
2009	1,391	14,213	25.28	61.43	0.33	725,366	290,815
2010	865	9,585	25.41	62.00	0.32	761,493	297,975
2011	1,495	14,689	24.76	59.36	0.35	801,674	305,564
2012	1,553	13,357	25.33	59.48	0.00	844,636	313,384
2013	1,599	22,097	24.63	55.07	0.10	888,542	321,564
2014	2,088	28,471	25.13	58.67	0.03	939,371	329,656
2015	2,053	23,579	27.33	59.39	0.10	990,856	338,186
2016	1,846	17,391	27.79	57.64	0.11	1,043,748	347,400

Table A.4: Country level 1 – Conflicts, GDP and population

	Number of conflicts (sum)	Number of deaths (sum)	GDP country (sum)	POP country (sum)	Average grid-cell GDP	Average grid-cell POP
Algeria	4108	27012	6,305,072,001	865,756,777	915,769	125,745
Angola	1680	59745	1,641,228,528	417,298,984	474,893	120,746
Benin	0	0	277,328,449	223,016,241	540,601	434,730
Botswana	1	1	612,140,650	48,575,249	343,513	27,259
Burkina Faso	1	25	402,467,426	367,807,856	382,210	349,295
Burundi	1429	25635	67,486,692	205,650,224	416,585	1,269,446
Cameroon	246	3835	885,631,058	445,239,589	537,724	270,334
Central African Republic	880	8804	73,047,212	133,276,192	37,061	67,619
Chad	338	19393	452,105,903	269,205,561	122,224	72,778
Congo	230	16770	282,404,436	84,504,258	222,541	66,591
Cote d'Ivoire	273	3509	791,639,927	472,601,321	771,579	460,625
Democratic Rep. of Congo	2841	116712	437,634,131	1,567,352,562	68,973	247,022
Djibouti	46	743	39,862,594	20,884,312	210,913	110,499
Egypt	568	3028	9,386,769,562	2,242,553,280	3,249,141	776,239
Equatorial Guinea	0	0	146,723,443	9,154,001	679,275	42,380
Eritrea	96	128766	74,963,060	122,953,914	115,684	189,744
Ethiopia	1763	64007	1,292,081,567	1,974,790,450	398,791	609,503
Gabon	0	0	459,624,464	33,160,445	515,852	37,217
Gambia	0	0	47,093,979	42,597,557	436,055	394,422
Ghana	38	2472	672,986,984	571,233,911	804,047	682,478
Guinea	78	1559	192,748,702	191,725,094	223,089	221,904
Guinea Bissau	22	758	17,717,794	38,140,147	109,369	235,433
Kenya	730	5777	1,277,279,553	935,717,887	716,767	525,094
Lesotho	4	68	65,592,763	52,002,006	269,929	214,000
Liberia	536	25263	26,832,795	67,528,941	82,817	208,423
Libya	654	9693	2,181,880,003	155,484,365	464,427	33,096
Madagascar	42	207	404,793,941	473,529,794	223,767	261,763
Malawi	0	0	228,599,087	349,096,862	403,173	615,691
Mali	358	4100	321,180,473	308,655,594	84,366	81,076
Mauritania	14	244	120,534,437	74,293,885	39,507	24,351
Morocco	4	67	2,897,026,108	787,682,744	1,262,321	343,217
Mozambique	163	4518	411,300,103	532,762,202	155,442	201,346
Namibia	20	101	293,200,006	52,212,546	122,014	21,728
Niger	152	1741	206,951,344	351,530,935	58,510	99,387
Nigeria	2994	51758	5,458,434,477	3,245,232,241	2,150,683	1,278,657
Rwanda	613	550061	224,583,832	237,963,165	1,663,584	1,762,690
Senegal	272	1833	320,372,183	203,392,816	439,468	279,002
Sierra Leone	1492	28698	71,651,834	115,358,745	331,721	534,068
Somalia	4055	53022	198,523,794	225,441,748	98,036	111,329
South Africa	2561	6631	10,040,669,914	1,170,601,836	2,754,642	321,153
Sudan	3391	171940	1,720,722,835	965,102,867	252,899	141,843
Swaziland	0	0	130,563,591	29,196,250	690,813	154,478
Tanzania	12	67	1,103,763,914	1,014,016,132	408,801	375,562
Togo	106	586	124,482,117	162,873,209	354,650	464,026
Tunisia	2	59	1,753,178,111	263,969,607	2,164,417	325,888
Uganda	1645	17407	721,170,350	764,626,149	861,613	913,532
Zambia	10	51	356,667,687	300,513,509	148,426	125,058
Zimbabwe	54	314	74,919,123	344,540,366	51,385	236,310

Table A.5: Country level 2 – Climate

	Temperature (mean) ° Celsius	Diff_temp. 1990-2016*	Precipitation (mean) mm/day	Diff_prec. 1990-2016*	SPI-12 (mean)
Algeria	23.99	3.38	7.93	3.24	0.35
Angola	23.12	2.74	71.36	-18.30	-0.30
Benin	27.83	1.31	92.61	23.64	-0.03
Botswana	23.22	2.85	28.17	-8.29	-0.28
Burkina Faso	28.55	1.50	77.60	31.65	-0.06
Burundi	23.05	1.53	96.61	-26.43	-0.03
Cameroon	26.01	1.99	135.06	32.81	-0.03
Central African Republic	26.35	1.76	120.70	27.46	-0.19
Chad	28.30	2.27	37.34	19.36	0.18
Congo	25.77	1.43	128.22	-9.07	-0.25
Cote d'Ivoire	26.32	0.88	127.98	37.90	-0.08
Democratic Republic of Congo	25.23	1.75	119.64	-5.15	-0.24
Djibouti	28.20	1.54	30.11	3.42	0.13
Egypt	23.74	2.01	3.12	-0.63	0.33
Equatorial Guinea	26.16	1.91	174.40	-0.43	-0.15
Eritrea	27.89	2.03	25.44	14.33	-0.08
Ethiopia	24.73	2.21	64.32	15.19	0.11
Gabon	25.81	1.55	143.36	-14.85	-0.23
Gambia	27.12	0.72	99.18	43.91	-0.21
Ghana	27.49	0.70	98.90	20.97	-0.16
Guinea	26.12	1.69	161.02	68.11	-0.19
Guinea Bissau	26.87	0.68	142.83	62.13	-0.23
Kenya	25.57	1.53	62.39	-1.19	0.08
Lesotho	14.49	2.97	52.72	-20.63	-0.58
Liberia	25.64	0.91	206.82	69.16	-0.03
Libya	23.49	2.31	3.49	-0.69	0.26
Madagascar	23.26	1.47	114.11	-36.56	0.16
Malawi	23.89	2.21	73.23	-31.57	-0.51
Mali	28.87	2.15	37.74	23.26	0.19
Mauritania	28.33	1.79	13.75	11.44	0.19
Morocco	20.70	1.84	14.87	2.86	-0.02
Mozambique	24.35	1.24	70.96	-26.95	-0.29
Namibia	21.55	2.85	20.40	-11.27	-0.28
Niger	28.68	2.40	24.01	13.28	0.20
Nigeria	27.47	1.53	105.92	32.55	0.09
Rwanda	22.27	1.07	105.36	-11.51	0.02
Senegal	27.87	0.66	77.04	38.99	-0.17
Sierra Leone	26.36	1.21	225.70	89.60	-0.24
Somalia	27.34	1.47	27.57	5.93	0.25
South Africa	18.75	2.10	36.65	-9.51	-0.28
Sudan	28.47	2.61	44.50	20.12	0.03
Swaziland	19.43	1.81	61.71	-15.79	-0.32
Tanzania	23.54	1.40	82.98	-23.38	-0.06
Togo	27.87	1.04	98.10	24.07	-0.13
Tunisia	20.84	1.75	21.28	-2.92	0.12
Uganda	23.64	2.01	103.68	10.15	-0.02
Zambia	23.49	2.23	72.99	-30.47	-0.25
Zimbabwe	23.26	2.33	47.57	-12.24	-0.16

*Notes: * Differences in temperature and precipitation are calculated from the average values of the first and last 3 years (1990-1992 and 2014-2016).*

Table A.6: Aqueduct Water Risk Atlas indicators

Code	Variable name	Calculation
BWS	Baseline Water Stress *It is calculated by dividing water withdrawals by mean available blue water (1950–2010). Higher values indicate more competition among users. Areas with available blue water and water withdrawal less than 0.03 and 0.012 m/m2 respectively are coded as "arid and low water use". Arid areas with low water use are scored as high stress when calculating aggregated scores.*	(LN([raw_value])-LN([c1]))/LN([base])+1 *Low (<10%)* *Low to medium (10-20%)* *Medium to high (20-40%)* *High (40-80%)* *Extremely high (>80%)*
WSV	Inter-annual Variability *It is given by the Standard deviation of annual total blue water divided by the mean of total blue water (1950–2008).*	([raw_value]-[c1])/[base]+1 *Low (<0.25)* *Low to medium (0.25-0.5)* *Medium to high (0.5-0.75)* *High (0.75-1.0)* *Extremely high (>1.0)*
SV	Seasonal Variability *It is given by the standard deviation of monthly total blue water divided by the mean of monthly total blue water (1950–2008). The means of total blue water for each of the 12 months of the year were calculated, and the variances estimated between the mean monthly values.*	([raw_value]-[c1])/[base]+1 *Low (<0.33)* *Low to medium (0.33-0.66)* *Medium to high (0.66-1.0)* *High (1.0-1.33)* *Extremely high (>1.33)*
HFO	Flood Occurrence *It is given by the number of flood occurrences between 1985 and 2011. Flood counts were calculated by intersecting hydrological units with estimated flood extent polygons.*	(LN([raw_value])-LN([c1]))/LN([base])+1 *Low (0-1)* *Low to medium (2-3)* *Medium to high (4-9)* *High (10-27)* *Extremely high (>27)*
DRO	Drought Severity *Drought severity is the mean of the lengths times the dryness of all droughts occurring in an area. Drought is defined as a contiguous period when soil moisture remains below the 20th percentile. Length is measured in months, and dryness is the average number of percentage points by which soil moisture drops below the 20th percentile. Drought data is resampled from original raster form into hydrological catchments.*	([raw_value]-[c1])/[base]+1 *Low (<20)* *Low to medium (20-30)* *Medium to high (30-40)* *High (40-50)* *Extremely high (>50)*

Table A.7: Polity components and Polity2 index

<u>DEMOCRACY</u> is conceived as three essential and interdependent elements: 1. The presence of institutions and procedures through which citizens can express effective preferences about alternative policies and leaders; 2. The existence of institutionalized constraints on the exercise of power by the executive; 3. The guarantee of civil liberties to all citizens in their daily lives and in acts of political participation. Other aspects of plural democracy, such as the rule of law, systems of checks and balances, freedom of the press, and so on are means to, or specific manifestations of, these general principles. We do not include coded data on civil liberties. *The Democracy indicator is an additive eleven-point scale (0-10). The operational indicator of democracy is derived from coding of (and weighting) the competitiveness of political participation (competitive, transitional, factional), the openness (dual, election) and competitiveness (election, transitional) of executive recruitment, and constraints on the chief executive (executive parity or subordination, intermediate category, substantial limitations).*
<u>AUTOCRACY</u> Considering an authoritarian regime as characterized by a lack of regularized political competition and concern for political freedoms, "Autocracy" is define in terms of the presence of a distinctive set of political characteristics. In mature form, autocracies sharply restrict or suppress competitive political participation; their chief executives are chosen in a regularized process of selection within the political elite, and once in office they exercise power with few institutional constraints. Most modern autocracies also exercise a high degree of directiveness over social and economic activity, but we regard this as a function of political ideology and choice, not a defining property of autocracy. *An eleven-point Autocracy scale is constructed additively. Our operational indicator of autocracy is derived from codings of (and weighting) the competitiveness of political participation (repressed, suppressed), the regulation of participation (restricted, sectarian), the openness (closed, dual/designation) and competitiveness (selection) of executive recruitment and constraints on the chief (unlimited authority, intermediate category, slight to moderate limitations).* *The logic of this "institutionalized autocracy" scale is similar to that of the institutionalized democracy scale but the two scales do not share any categories in common.*
<u>Polity2</u> is a modified version of the POLITY score that is computed by subtracting the AUTOC score from the DEMOC score; the resulting unified polity scale ranges from +10 (strongly democratic) to -10 (strongly autocratic). Polity2 modifies the combined annual POLITY score by applying a simple treatment to convert instances of "standardized authority scores" to conventional polity scores (within the range -10 to +10). The values have been converted according to the following rule set: -66: Cases of foreign "interruption" are treated as "system missing"; -77: Cases of "interregnum" or anarchy, are converted to a "neutral" Polity score of "0"; -88: Cases of "transition" are prorated across the span of the transition. *For example, country X has a POLITY score of -7 in 1957, followed by three years of -88 and, finally, a score of +5 in 1961. The change (+12) would be prorated over the intervening three years at a rate of per year, so that the converted scores would be as follows: 1957 -7; 1958 -4; 1959 -1; 1960 +2; and 1961 +5.*

Table A.8: Political Risk Components (PRS) components

<u>Government stability</u>: (12 points) this is an assessment of the government's ability to carry out its declared program(s) and its ability to stay in office. The risk rating assigned is the sum of three subcomponents: Government Unity, Legislative Strength, Popular Support. Each component can be assigned with a maximum score of four points and a minimum score of 0 points. A score of 4 points equates to Very Low Risk and a score of 0 points to Very High Risk.
<u>Investment profile</u>: (12 points) this is an assessment of factors affecting the risk to investment that are not covered by other political, economic and financial risk components. The risk rating assigned is the sum of three subcomponents: Contract Viability or Expropriation, Profits Repatriation, Payment Delays. Each component can be assigned with a maximum score of four points and a minimum score of 0 points. A score of 4 points equates to Very Low Risk and a score of 0 points to Very High Risk.
<u>Socio-economic conditions</u>: (12 points) this is an assessment of the socioeconomic pressures at work in society that could constrain government action or fuel social dissatisfaction. The risk rating assigned is the sum of three subcomponents: Unemployment, Consumer Confidence, Poverty. Each component can be assigned with a maximum score of four points and a minimum score of 0 points. A score of 4 points equates to Very Low Risk and a score of 0 points to Very High Risk.
<u>Corruption:</u> (6 points) this measure of corruption is concerned with actual or potential corruption in the form of excessive patronage, nepotism, job reservations, 'favor-for-favors', secret party funding, and suspiciously close ties between politics and business, as forms of potential greater risk to foreign business in that they can lead to popular discontent, unrealistic and inefficient controls on the state economy, and encourage the development of the black market. The greatest risk is that at some time it will become so overweening as to provoke a popular backlash, resulting in a fall or overthrow of the government, a major reorganizing or restructuring of the country's political institutions, or, at worst, a breakdown in law and order, rendering the country ungovernable.
<u>Military in politics</u>: (6 points) the involvement of military (not elected by anyone) in politics is a diminution of democratic accountability. However, it also has other significant implications, as for example, become involved in government because of an actual or created internal or external threat. In some countries, the threat of military take-over can force an elected government to change policy or cause its replacement by another government more amenable to the military's wishes. A military takeover or threat of a takeover may also represent a high risk if it is an indication that the government is unable to function effectively, and that the country therefore has an uneasy environment for foreign businesses. A full-scale military regime poses the greatest risk. In the short term a military regime may provide a new stability and thus reduce business risks. However, in the longer term the risk will almost certainly rise, partly because the system of governance will be become corrupt and partly because the continuation of such a government is likely to create an armed opposition. In some cases, military participation in government may be a symptom rather than a cause of underlying difficulties. Overall, lower risk ratings indicate a greater degree of military participation in politics and a higher level of political risk.
<u>Religious tensions</u>: (6 points) religious tensions may stem from the domination of society and/or governance by a single religious group that seeks to replace civil law by religious law and to exclude other religions from the political and/or social process; the desire of a single religious group to dominate governance; the suppression of religious freedom; the desire of a religious group to express its own identity, separate from the country as a whole. The risk involved in these situations range from inexperienced people imposing inappropriate policies through civil dissent to civil war.
<u>Law and order</u>: (6 points) "Law and Order" form a single component, but its two elements are assessed separately, with each element being scored from zero to three points. To assess the "Law" element, the strength and impartiality of the legal system are considered, while the "Order" element is an assessment of popular observance of the law. Thus, a country can enjoy a high rating – 3 – in terms of its judicial system, but a low rating – 1 – if it suffers from a very high crime rate if the law is routinely ignored without effective sanction (for example, widespread illegal strikes).
<u>Ethnic tensions</u>: (6 points) this component is an assessment of the degree of tension within a country attributable to racial, nationality, or language divisions. Lower ratings are given to countries where racial and nationality tensions are high because opposing groups are intolerant and unwilling to compromise. Higher ratings are given to countries where tensions are minimal, even though such differences may still exist.
<u>Democratic accountability</u>: (6 points) this is a measure of how responsive government is to its people, on the basis that the less responsive it is, the more likely it is that the government will fall, peacefully in a democratic society, but possibly violently in a non-democratic one. The points in this component are awarded on the basis of the type of governance enjoyed by the country in question. For this purpose, we have defined the following types of governance: Alternating democracy, dominated democracy, de facto one-party state, de jure one-party state, autarchy.
<u>Bureaucracy Quality</u>: (4 points) the institutional strength and quality of the bureaucracy is another shock absorber that tends to minimize revisions of policy when governments change. Therefore, high points are given to countries where the bureaucracy has the strength and expertise to govern without drastic changes in policy or interruptions in government services. In these low-risk countries, the bureaucracy tends to be somewhat autonomous from political pressure and to have an established mechanism for recruitment and training. Countries that lack the cushioning effect of a strong bureaucracy receive low points because a change in government tends to be traumatic in terms of policy formulation and day-to-day administrative functions.

Table A.9: CACAO: List of variables

Variable	Description	Source
nc	Number of conflicts	UPPSALA
cd	Conflict dummy	UPPSALA
nd	Number of deaths (best, low, high, deaths_nz)	UPPSALA
p	Precipitation (yearly value, mm)	Our elaboration from AFDM
pm5	Precipitation (average w.r.t t-5)	Our elaboration from AFDM
pm10	Precipitation (average w.r.t t-10)	Our elaboration from AFDM
psd5	Precipitation (standard deviation w.r.t t-5)	Our elaboration from AFDM
psd10	Precipitation (standard deviation w.r.t t-10)	Our elaboration from AFDM
s	SPI-12 (yearly value)	Our elaboration from AFDM
sm5	SPI-12 average (w.r.t t-5)	Our elaboration from AFDM
sm10	SPI-12 (average w.r.t. t-10)	Our elaboration from AFDM
t	Temperature (yearly value, °C)	Our elaboration from AFDM
tm5	Temperature (average w.r.t. t-5)	Our elaboration from AFDM
tm10	Temperature (average w.r.t. t-10)	Our elaboration from AFDM
tsd5	Temperature (standard deviation w.r.t. t-5)	Our elaboration from AFDM
tsd10	Temperature (standard deviation w.r.t. t-10)	Our elaboration from AFDM
gdp	Gross Domestic Product (Thousands of US$ PPP constant 2005)	SEDAC
gdp1	Gross Domestic Product (t-1) (Thousands of US$ PPP constant 2005)	SEDAC
pct	Gross Domestic Product per capita (Thousands of US$ PPP constant 2005)	Our elaboration from SEDAC
pct1	Gross Domestic Product per capita (t-1) (Thousands of US$ PPP constant 2005)	Our elaboration from SEDAC
pcvar	Change in GDP per capita (t; t-1)	Our elaboration from SEDAC
pop	Population (Population number)	SEDAC
GDP_sh	Share between GDP_cell and GDP_country (by year)	Our elaboration from SEDAC
GDP_ln	Ln of the share between GDP_cell and GDP_country_average (by year)	Our elaboration from SEDAC
GINI	Gini index (each cell w.r.t. country and year)	Our elaboration from SEDAC
resources	Presence of mineral and fossil fuel resources (dummy)	Our elaboration from Data Basin Dataset
forest	Presence of forests (dummy)	Our elaboration from Global Land Cover dataset
rural	Presence of rural areas (dummy)	Our elaboration from Global Land Cover dataset
fuel	Fuel exports (% of merchandise exports)	World Bank
min	Ores and metals exports (% of merchandise exports)	World Bank
agr	Agriculture value added (% of GDP)	World Bank
bws	Baseline Water Stress (total annual water withdrawals index)	Aqueduct Water Risk Atlas
dro	Drought Severity (av. length of drought * dryness of droughts 1901-2008)	Aqueduct Water Risk Atlas
flood	Flood Occurrence (number of floods recorded from 1985 to 2011)	Aqueduct Water Risk Atlas
sv	Seasonal variability	Aqueduct Water Risk Atlas
wsv	Inter-annual variability	Aqueduct Water Risk Atlas
w_agr	Default agriculture sector weight overall water risk (areas with higher exposure to water-related risks for the agricultural sectors)	Aqueduct Water Risk Atlas
bur	Bureaucracy Quality	PRS Group
corru	Corruption	PRS Group
democ	Democratic accountability	PRS Group
socio_eco	Socio-economic conditions	PRS Group

eth	Ethnic tensions	PRS Group
gov	Government stability	PRS Group
invp	Investment profile	PRS Group
law	Law and order	PRS Group
milit	Military in politics	PRS Group
relig	Religious tensions	PRS Group
prs	Overall PRS Institutional index	Our elaboration on PRS Group
pol2	Polity2 Democracy Index	Polity database
col_fra	French colony (dummy)	CIA
col_port	Portuguese colony (dummy)	CIA
col_uk	British colony (dummy)	CIA
col_bel	Belgian colony (dummy)	CIA
col_spa	Spanish colony (dummy)	CIA
col_ita	Italian colony (dummy)	CIA
col_oth	Other colony (dummy)	CIA
col_y	Independence year	CIA
Poverty_WB	Low-income economies classification according to the World Bank Atlas method (dummy)	World Bank
Poverty_WB2	Low and lower middle-income economies classification according to the World Bank Atlas method (categorical variable)	World Bank
Poverty_06	Countries are classified as 'poor' if below the 60% of median African income (dummy)	World Bank
Poverty_05	Countries are classified as 'poor' if below the 50% of median African income (dummy)	World Bank
FDI	Foreign direct investment, net inflows (% of GDP)	World Bank

Figure A.1: Number of conflicts by country and year

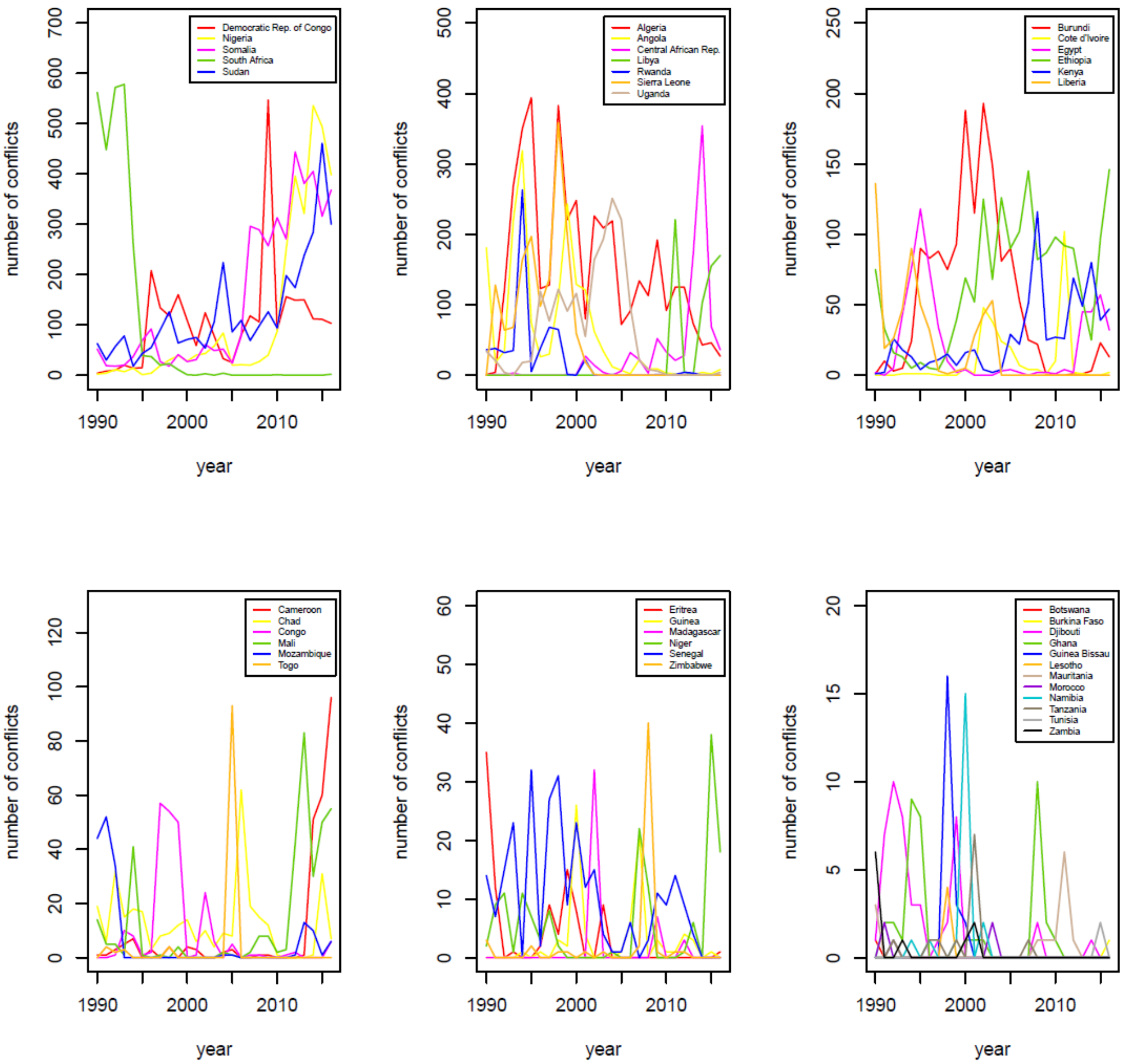
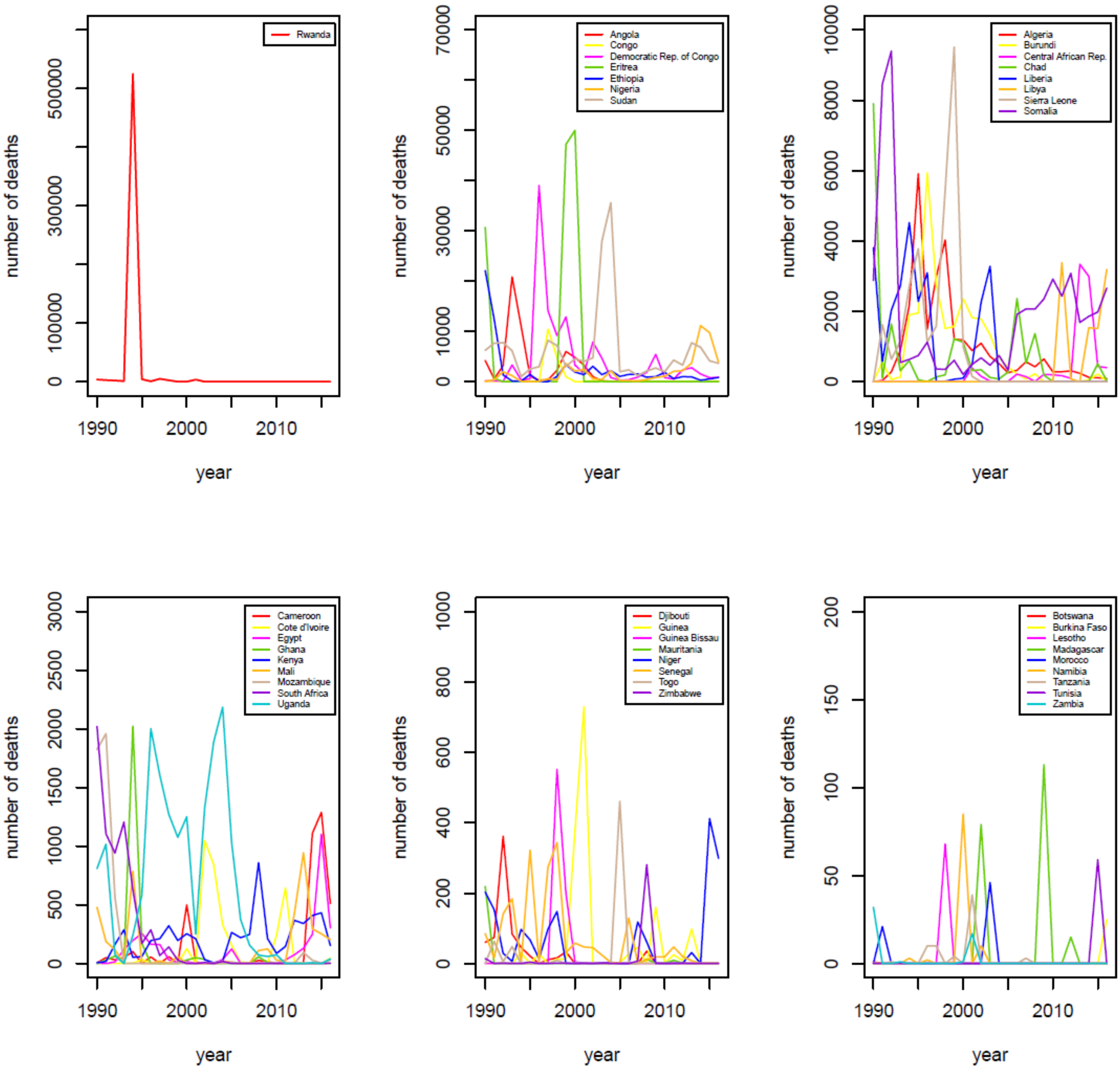


Figure A.2: Number of deaths by country and year



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