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The need for willingness and opportunity: analyzing where and when environmental variability influences conflict in the Sahel

Justin Schon[1] · **Britt Koehnlein**[2] · **Ore Koren**[2]

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Abstract

Researchers and policymakers often claim that harsh climate conditions intensify the risk of armed conflict by acting as a "threat multiplier." Yet, new data reveal that locations with seasonal environmental variations face higher conflict risk than locations with permanently harsh climate, e.g., due to the ability of populations accustomed to harsh climatic conditions to develop adaptation practices. Focusing on the Sahel, we investigate underexplored relationships between the location and timing of environmental and agricultural resource variability, and their impact on conflict. We argue that in Sahara Desert transition locations, harsh climate gives people a greater willingness to engage in competitive violence over resources compared with other locations. However, this will happen only in times of relatively high levels of environmental security and agricultural resource abundance, which give people the opportunity to act on these incentives. We test this argument on a new monthly dataset of 0.5 by 0.5-degree grid cells covering the entire African continent and find robust support for our expectations. In illustrating that both spatially and temporally disaggregated data are necessary for understanding climate-conflict relationships, our findings delineate new directions of research and policymaking.

Keywords Climate · Conflict · Africa · Sahara · Sahel

✉ Justin Schon
jschon7@gmail.com

Britt Koehnlein
bdkoehnl@iu.edu

Ore Koren
okoren@iu.edu

[1] College of William & Mary, AidData, Williamsburg, VA, USA

[2] Department of Political Science, Indiana University Bloomington, Bloomington, IN, USA

Introduction

The notion that harsh climate can fuel conflict in susceptible areas, and particularly in the Sahel, is increasingly accepted by policymakers (e.g., Banerjee, 2019; Evans, 2011; Gilmore & Buhaug, 2021; Mobjörk et al., 2020; Muggah & Cabrera, 2019; Reiling & Brady, 2015). Yet, research is still exploring exactly if, when, and how climate variations shape conflict trends across different contexts (see, e.g., von Uexkull & Buhaug, 2021). One perspective advocated by many studies is that climate-induced threats and their impact on environmental security operate as a "threat multiplier," increasing conflict risk and aggravating the impact of ongoing crises and adverse socioeconomic conditions on political stability (Ide et al., 2020; Raleigh et al., 2015; Scheffran et al., 2014). A particular focus of these studies has been environmental security in the transition zone between the African Sahel and the Sahara Desert, where harsh climate conditions strain historically tense relationships between agricultural and pastoralist communities, potentially feeding into insurgencies (Butler & Gates, 2012; Detges, 2017; Dowd & Raleigh, 2013; Hendrix & Salehyan, 2012; Raleigh, 2010; Raleigh & Kniveton, 2012; Raleigh et al., 2015; von Uexkull & Buhaug, 2021).

The focus on climate stress as a conflict risk multiplier is useful, but this perspective risks missing some important relationships, especially when considering that environmental impacts are complex and vary across locations and times (O'Loughlin et al., 2012; Theisen et al., 2013; von Uexkull et al., 2016). Focusing on seasonal variations in agricultural resource productivity, a key part of oft-used definitions of environmental security (e.g., Graeger, 1996), we test one underexplored relationship, which we believe will become increasingly more important in the future if current climate trends persist. Specifically, we argue that if climate stress can incentivize violence, these effects will be more likely in locations where environmental conditions are only sometimes, not always, harsh. Particularly, we focus on climate stress–prone areas where sudden improvement and decline in environmental health are a standard feature.

In developing our theory, we link climate stress and environmental security by building on conflict research frameworks that conceptualize conflict onset based on both the *willingness* to engage in violence and the *opportunity* to do so (Siverson & Starr, 1991). According to our expectations, as well as several past studies (e.g., Koren & Bagozzi, 2016; Maystadt & Ecker, 2014; McGuirk & Burke, 2020; Weinberg & Bakker, 2015), the willingness to fight will be higher *where* climate conditions are harsher, which creates competition over agricultural resources, food, and water. Willingness alone, however, is often insufficient in explaining conflict; unless there is an *opportunity* to engage in violence, individuals and groups are unlikely to do so. To approximate opportunity from an environmental-centric perspective, we incorporate environmental seasonality, which—although used in some studies (e.g.,Crost & Felter, 2020; Landis, 2014; Linke & Ruether, 2021; Raleigh & Kniveton, 2012)—is still underexplored in a systematic way, locally as well as across different countries and contexts, in climate-conflict nexus research.

We argue that while climate harsh locations are more likely to induce willingness on the part of military and rebels to engage in violence along resource scarcity lines, they will only act on these incentives *when* environmental conditions improve. In these times, more resources are available, facilitating military operations and allowing groups and military organizations—especially those living off locally sourced food—to support their troops effectively. This view is in line with studies that highlight the role of agricultural resource abundance in driving conflict (Crost & Felter, 2020; Koren, 2018, 2019; Koren & Bagozzi, 2016; Linke & Ruether, 2021).

To test these claims, we rely on AfroGrid, a recently released dataset incorporating a wide variety of conflict, development, and climate variables measured at the 0.5-degree cell-month level (Schon & Koren, 2022). With these data, we deploy several ordinary least squares (OLS) models—as recommended in extant econometric research (Angrist & Pischke, 2008)—to test our conditional hypotheses, accounting for key local development and population levels, as well as conflict persistence and other temporal and country-level dependencies and heterogeneities, and find robust support for these claims. Most interestingly, we find that (i) the frequency of attacks by both state forces and rebels in climate harsh Sahara Desert transition zones increases during times of greater environmental security and agricultural resource abundance, although (ii) no intensification of attacks by local militias and other non-state actors is observed, and (iii) that during times of low environmental security and resource scarcity, all actors are significantly less likely than average to initiate attacks within these Sahara Desert transition zones compared with other regions. By marrying motivation with opportunity from an environmentally centric perspective, our research hence helps bridge the gap between scarcity focused studies and research showing that conflict intensifies where and when there is agricultural abundance. We conclude with a discussion of our findings' implications for research and policy.

Key concepts

Our theoretical argument and empirical evaluation both rely on a set of specific concepts. The first is environmental security. For our purposes, *environmental security* is defined as the "health" of a given location as it pertains to aspects such as agricultural production, soil erosion, deforestation, and air and water quality (see, e.g., Graeger, 1996). Definitions of environmental security often focus on the sustainable utilization of the environment, especially with respect to (agricultural) resource availability and access (Buzan et al., 1998). Considering these issues, we theorize—and operationalize—environmental security as the degree of health of the local vegetation (empirically using the normalized difference vegetation index (NDVI), as discussed below). As such, we are able to proxy local levels of agricultural sustainability in a comparable manner across all African locations, creating a theory for operationalizing direct impacts of environmental variations rather than using climate proxies.

Accordingly, we distinguish between environmental security and *harsh climatic conditions*. While the latter obviously have some implications for environmental security, climatic conditions are nevertheless distinct phenomena. So, for instance, climate proxies with relevant implications (e.g., temperature, rainfall) have been heavily deployed in climate-conflict research (e.g.,Hendrix & Salehyan, 2012; Raleigh & Kniveton, 2012; Von Uexkull et al., 2016). However, environmental security can exist even in areas where such proxies show extremely high/low values. An area could have a high level of vegetative health even during drought, for instance, because it is located downstream from a reservoir, or because the crops produced are drought resistant. At the same time, climate harsh areas do make it, on average, harder to achieve environmental security throughout the year, which can shape the incentive structure of armed actors.

We hence theorize that climate and environmental conditions can involve different pathways and different direct impacts, while also recognizing the mutual relationship between the two. Our decision to focus on the Sahara Desert transition zone within the Sahel is directly motivated by our aim of studying this important interaction (we discuss our operationalization procedure designed to capture these aspects in the empirical section). Such areas are defined by the year-round existence of climate harsh conditions, but also exhibit marked variability with respect to environmental conditions and environmental security (as defined above). Importantly, past research (Benjaminsen et al., 2012; Dowd & Raleigh, 2013; Raleigh, 2010) has highlighted these issues when studying violence in the Sahara Desert transition zones, with some studies underscoring and others disputing the potential role of climatic stress in these regards (Detges, 2017; Hendrix & Salehyan, 2012; Raleigh, 2010; Raleigh & Kniveton, 2012).

Finally, our theoretical and empirical definitions of “conflict” similarly build on past research that specifically focused on civil wars and insurgencies, namely battles between state forces and armed groups (see, e.g., Collier & Hoeffler, 2004; Homer-Dixon, 1994; Koren & Bagozzi, 2016; von Uexkull et al., 2016). Here, we are also motivated by recent concerns raised by policymakers about potential linkages between climate and organized insurgency in the Sahel (e.g., Evans, 2011; Muggah & Cabrera, 2019). Note that—due to our focus on insurgency—we do not theorize about other forms of conflicts between nonstate actors, although we do test whether our theory is empirically relevant to such dynamics. There are different theoretical, the fact that nonstate actors (e.g., farmer-herder, multiple ethnic militias) may have different motivations and opportunities to engage in violence, and empirical—often, such conflicts focus on areas such as pastureland or spread over wide areas, which we cannot effectively proxy in our models—reasons that we choose to focus specifically on insurgency. By demonstrating a planned and strategic desire to confront the state and for the state to eliminate its opponents, battles are one of the clearest indicators of insurgency. Accordingly, as we discuss below, we take a broad empirical definition of conflict, relying on data from two different datasets—and focusing on both events that involve casualties and those that do not, as well as events happening as part of a war and those that do not—in our analytical models. This helps in ensuring that any results identified are robust to the underlying measurement choices employed across different databases.

Environmental insecurity as a threat multiplier

Our argument focuses on the Sahara Desert transition zones within the Sahel's distinction because of its particular susceptibility to climate change-related threat multiplier risks. Climate risk—defined broadly as a "condition under which the effects of climate variability and/or change are represented as threatening to a group of affected actors" (Mason, 2014: 807)—presents a threat that may yield a variety of responses. Climate-conflict research has developed a consensus that harsh conditions do not automatically trigger conflict, but numerous studies argue that climate stress can act as a "threat multiplier" in locations with social, economic, and political conditions already susceptible to insecurity (e.g., Ide et al., 2020; Raleigh et al., 2015; Scheffran et al., 2014; von Uexkull et al., 2016). In particular, threat multiplier centric arguments highlight the capability of climatic stress to aggravate existing *grievances*, and—correspondingly—the ability of societies to adapt to environmental conditions if they possess sufficient state capacity and tools for resilience. Climate stress may aggravate existing grievances by exacerbating political and economic inequality, intensifying competition over agricultural resources, increasing strains on food and herding systems, and weakening state capacity (Adano et al., 2012; Bellemare, 2015; Döring, 2020; Ide, 2016; Koren & Bagozzi, 2016; von Uexkull et al., 2016). Extreme rainfall deviations (floods and droughts) have been shown to increase rebel and communal conflicts by inducing scarcity shocks and exacerbating competition over resources (Hendrix & Salehyan, 2012; Raleigh & Kniveton, 2012).

Similarly, state responses to climatic stress play a critical role in influencing whether violence may arise due to widespread grievances. For instance, Regan and Kim (2020) argue that greater levels of governmental adaptive capacity can lead to a lower likelihood of armed conflict in response to water scarcity. Döring (2020) shows the risk of groundwater shortages leading to conflict decreases in areas with a greater state presence, for example, because states may implement a variety of irrigation schemes including dams, canals, and boreholes to reduce grievances over water-sharing. Similarly, Detges (2017) finds that droughts increase support for political violence only where states do not provide social safety nets and other means of addressing the stress experienced by civilians, which causes anti-state grievances to fester.

Another way state responses to climate stress may aggravate grievances is by reinforcing horizontal inequalities between groups. For example, von Uexkull et al. (2016) find that droughts increase the risk of conflict only among populations that are already ethnically and socioeconomically marginalized, where anti-regime grievances are prevalent. Similarly, Homer-Dixon (1994) observes that in the 1970s, the prospect of chronic food shortages and a serious drought led to dams being built in Mali and on the border of Senegal and Mauritania. Elites in Senegal and Mauritania responded to the resultant change in land values by shifting property rights and resource distribution in their own favor, which produced a sudden increase in resource scarcity for one ethnic minority (black Africans/Moors), expulsion of other minorities, and ethnic violence.

The threat multiplier argument, therefore, suggests that remote locations subject to harsh climate conditions are particularly likely to experience grievances that can lead to anti-government attacks, and therefore to conflict involving state forces and insurgents. Building on research and policy discussed in the previous section, which (as discussed above) identified the Sahara Desert transition zones within the Sahel as especially susceptible to climate-induced threat multiplier risks via intensifying grievances (Detges, 2017; Hendrix & Salehyan, 2012; Raleigh, 2010; Raleigh & Kniveton, 2012), we derive the following hypothesis:

H1: Sahara Desert transition zones experience a higher rate of conflicts.

Seasonal variations and opportunity for conflict

Emphasizing the role of harsh climatic conditions as multiplying the threat of grievance-driven conflict has yielded useful insights into possible climate-conflict nexus pathways, but it has two main shortcomings. First, this framework expects climate stress and the potentially resulting environmental scarcity to either increase conflict risk, or have no effect, but rarely examines scenarios where stress might lower the risk of violence. That does not mean that research has not analyzed how environmental and climatic shocks can produce positive peace outcomes (see, e.g., Ide et al., 2021), but rather that studies of the climate-conflict nexus have tended to focus—for relevant reasons—on the most adverse outcomes of such stressors. Yet, armed groups often reduce operations during times of environmental insecurity, and increase their attacks when environmental conditions are improved, which allows them to feed their troops and civilians living within territories they control and providing their troops with sufficient mobility capacity (Koren, 2018).

These claims have ample support in the extant research. For instance, Collier and Hoeffler (2004), Humphreys (2005), Buhaug et al. (2009), and Wood (2010) all link resource abundance to higher conflict incidence. These studies highlight mechanisms such as intensified rapacity, where armed actors seek to appropriate resources for consumption or revenue generation, and improved fighting capacity of troops, as the warring sides can convert resources into weapons and wages.

Second, the emphasis on grievances (and adverse climate conditions only) risks overpredicting conflict, considering their prevalence in many conflict and non-conflict contexts. As a result, researchers have become increasingly focused on the importance of *opportunity*, namely the conditions that allow for rebels to mobilize and insurgencies to fester (Collier & Hoeffler, 2004; Fearon & Laitin, 2003). Particularly, natural resource abundance, especially in remote areas within weak states, has been shown to be an important generator of such opportunities, owning, again, to the rapacity and capacity mechanisms outlined above (Buhaug et al., 2009; Collier & Hoeffler, 2004; Crost & Felter, 2020; Humphreys, 2005; Koren, 2018; Wood, 2010).

An especially relevant aspect of abundance in our case is *environmental security* (as defined in the previous section), which past research has shown is affecting both willingness and opportunity to engage in violence (e.g.,Koren, 2018; Koren & Bagozzi, 2016; Linke & Ruether, 2021; Weinberg & Bakker, 2015). Earlier in this paper, we distinguished between environmental insecurity and climate insecurity. From a grievance-centric perspective, climate harsh areas experience, on average, lower levels of environmental security, especially in weak states that do not have the capacity (or the will) to mitigate these impacts. Fewer food crop types may be grown in climate harsh areas, particularly when breakdowns in markets and supply chains are taken into account (Lin et al., 2021). With less crop diversification and income stability, regions may lose adaptive capacity and—by extension—environmental security (Brück & d'Errico, 2019). Facing acute environmental insecurity and a lack of state response, individuals may view participation in violence as a short-term way to address these adverse impacts (Adebayo & Oluwamayowa, 2021).

At the same time, environmental insecurity is not constant within climate harsh areas, and agricultural resource abundance often varies overtime. Accordingly, while grievances may be more likely to fester in these areas, this does not inevitably lead to conflict. Instead, in line with the rapacity-centric research discussed above, conflict rates will be dependent on environmental *opportunities* to engage in conflict. Without such opportunities, militaries and rebels might run into problems of fighting in areas that are generally inhospitable for organized warfare (Koren & Bagozzi, 2016). For instance, Somalia's 2011 drought arguably weakened Al Shabaab, reducing its opportunity to engage in conflict to the point that it was ousted from Mogadishu, due to the difficulty that the group faced in feeding both its fighters and local populations (Roble, 2011).

In line with this evidence, research shows that often, agricultural abundance—especially with respect to valuable food and cash crops—can provide opportunity for armed actors operating within developing states, and as such is associated with higher rates of conflict. One perspective links opportunity with the ability of organizations to recruit and mobilize. For instance, Crost and Felter (2020) find that higher productivity of banana crops within large plantations caused an increase in rates of rebel violence in the Philippines by incentivizing looting and facilitating recruitment. Similarly, Koren and Bagozzi (2016) find that access to more cropland is associated with higher rates of conflict, especially in regions where armies and rebels are unlikely to receive logistic support, a finding echoed by Koren (2018). Focusing on export goods in Africa, McGuirk and Burke (2020) likewise find that conflict rates increase in areas and years where productivity is high, as the abundance of export crops creates incentives for armed conflict for the purpose of appropriation, which is in line with some of Raleigh and Kniveton (2012) findings.

A second, related perspective associates opportunity with violence not because it helps troops recruit, but rather because attacking areas with greater agricultural abundance helps to weaken the other side. For example, Linke and Ruether (2021) find that violence during the Syrian civil war was often perpetrated by all sides to control agricultural areas or destroy them so that the other side could not obtain them. Koren (2019) finds similar trends in localized state-rebel conflicts in Sub-Saharan Africa.

There are also other explanations linking environmental security to higher conflict rates within our theoretical climate-conflict framework. One claim is that both rebels and state forces would prefer to operate during months when climatic conditions are relatively good, which makes military maneuvering easier. For example, in Afghanistan, the Taliban often waited for snow in the mountain passes to melt before resuming military activities (Landis, 2014). Moreover, in some regions, local populations have developed adaptation methods to survive (Horst, 2006), lowering the risk of grievance-driven conflict but also improving the ability of insurgents to persist in these regions. However, even these locations still face *seasonal* environmental insecurity (e.g., it might be harder to obtain food during late summer), which—absent of state or nonstate actor intervention and mitigation—can increase opportunistic incentives to engage in violence when environmental security is greater in order to increase resilience to future times of insecurity.

Building on the perspectives that emphasize grievances within climate harsh areas as well as the notion of environmental opportunity, we argue that conflict is unlikely to result from climatic conditions *unless there is both willingness and opportunity* to engage in it. By emphasizing the impact of climate stress on livelihoods via impacting grievances, threat multiplier centric perspectives effectively explain *where* climate insecurity leads to violence. Correspondingly, by emphasizing the role of opportunity for fighting, an abundance resource-driven perspective, which emphasizes environmental security, can explain *when* climatic conditions will cause rises in conflict within these susceptible areas.

Accordingly, we propose a conditional climate-centric theory of armed conflict (i.e., battles between the state and rebel/insurgent groups), where (i) grievances against the government in climate stress–susceptible areas will only lead to conflict when (ii) there is greater opportunity to engage in violence. We recognize that the role of grievances here is presumed rather than tested, but—as we mentioned in Concepts—ample research highlights the linkage between harsh climate and grievances in the Sahara Desert transition zones within the Sahel. This suggests the following interactive hypothesis to extend on H1:

> H2: Sahara Desert transition zones experience a higher rate of conflicts only during times of improved environmental conditions.

Data and methods

We test these hypotheses using a spatially and temporally disaggregated analysis of the AfroGrid dataset, a recently released dataset incorporating a wide variety of conflict, development, and climate variables measured at the 0.5-degree cell-month level (Schon & Koren, 2022).

We operationalize four dependent variables measuring battles between armed combatants (which adhere to our theoretical definition from above) using data from the Armed Conflict Location and Event Dataset (ACLED) (Raleigh et al., 2010) and the Uppsala Conflict Data Program's Georeferenced Event Dataset (UCDP GED) (Sundberg & Melander, 2013). These variables, all measured at the same cell-month level, are (i) *state battles (ACLED)*, which counts all battle events initiated by state forces from ACLED; (ii) *rebel battles (ACLED)*, which counts all battle events initiated by rebels and insurgents from ACLED; and (iii) *state battles (GED)*, which counts all conflict events involving state forces from GED. To test whether the argument is valid for other types of violence, we also include (iv) *nonstate battles (GED)*, which counts all conflict events between two nonstate actors from GED and does not capture our theoretical conceptualization of conflict as covered in the "Key concepts" section. Importantly, both ACLED and GED rely on different standards of measurement; ACLED defines events based on intent, even if they involved no casualties; GED codes events that involved at least one death and took place as part of a conflict with at least 25 combatant deaths. Both datasets hence capture a different aspect of our theoretical conceptualization of a conflict event discussed under the "Key concepts" section while relying on two data sources with distinct coding criteria, therefore helping to ensure that any observed relationships are empirically valid.

To test both hypotheses H1 and H2, we rely on the normalized difference vegetation index (NDVI), a continuous indicator of vegetation that serves as a proxy for agricultural productivity, which ranges from *possible* values of 0 (no vegetation) to 1 (the entirety of the cell-month is covered by vegetation) *on land*. NDVI does not distinguish between types of vegetation, but the raw measure does offer a straightforward indicator of the quantity of vegetation that is comparable across spatial units. It does not effectively distinguish between quantities of greenery across tropical areas, but it does effectively capture variation across arid and semi-arid locations that exhibit wider variation in vegetation quantity and have low to medium NDVI values (e.g., the Sahara transition zone that is the geographic focus of our analysis) (Anyamba & Tucker, 2005). It is possible for NDVI to detect greenery that is unrelated to agriculture, but high NDVI values do tend to suggest higher agricultural productivity (Schon et al., 2021). Since NDVI measures vegetation and rainfall fuels plants, rainfall intuitively has a positive effect on NDVI, yet rainfall levels do not guarantee NDVI levels will achieve a given value. Farmers may adapt to changing precipitation levels by adjusting how much they rely on irrigation, selecting different crop types to grow, or implementing other adaptations. NDVI therefore proxies environmental security more than climate security. NDVI information was downloaded from the MODIS Terra monthly satellite data and processed with the MODIStsp R package (Busetto & Ranghetti, 2016; Didan, 2015). Using these data, we construct two variables and interact them in our models below.

First, drawing on our theoretical discussion leading to hypothesis H1, we construct $\textit{Sahara transition zone}_{it}$, a dichotomous indicator marking whether a grid cell is part of the Sahara-Sahel transition zone, in three steps. The area we refer to as the Sahara-Sahel transition zone is a band stretching across the African continent. It marks the southern edge of the Sahara Desert and northern edge of the African Sahel and is characterized by harsh climatic conditions year-round. The conventional precipitation threshold for defining the Sahara Desert's boundary is usually 200 mm of annual rainfall (Tucker & Nicholson, 1999), but there are areas within this region with precipitation above 200 mm that can still face seasonal *environmental* insecurity.

We focus on this zone because it is particularly subject to harsh climate, and is projected to be heavily impacted by climate change and the expansion of the Sahara Desert. As Tucker and Nicholson (1999) observe, the green vegetation boundary of the Sahara fluctuates by up to 150 km from a wet year to a dry year. The transition zone from the southern boundary of the Sahara into the Sahel is often defined with an annual (climate-focused) precipitation band (Anyamba & Tucker, 2005), but as our theory suggests, incorporating monthly variation in the Sahara Desert's *vegetation* boundary can yield a more direct measure of the area inside the Sahara-Sahel transition zone as it relates to the intersection between climate harshness and environmental security. This transition zone includes areas with little pre-existing risk of violence, such as western Mali and southern Mauritania, and areas with a high pre-existing risk of violence, such as the border region of Mali-Burkina Faso-Niger, Lake Chad's surrounding area of Niger-Nigeria-Cameroon, and Darfur, Sudan, among other areas (Detges, 2017; Hendrix & Salehyan, 2012; Raleigh, 2010; Raleigh & Kniveton, 2012).

Accordingly, in the first step, we regress annual precipitation at the 0.5-degree grid cell level on average annual NDVI levels to identify the relationship between climatic conditions and environmental variability. Using the conventional climate-based definition of desertification (Tucker & Nicholson, 1999), we then calculate the predicted NDVI value when precipitation is at 200 mm or more. Our resultant predicted NDVI value is 0.192, which is directly within Herrmann et al. (2005) boundary of the Sahel between a minimum NDVI of 0.15 and a maximum NDVI of 0.4.

In the second step, we incorporate AfroGrid's monthly level advantage, counting the number of months in the year when each grid cell has an NDVI value below our predicted NDVI value of 0.192. If a grid cell's NDVI fails to reach our predicted environmental security threshold for 1–11 months during a given year, we define it as a desert transition zone. Locations that are environmentally insecure according to this metric always face desert-like conditions; locations that are never environmentally insecure based on this metric never experience desert-like conditions. A desert transition zone, by contrast, is temporarily environmentally insecure during parts of the year and experiences some level of relative security in others.

Third, drawing on our focus on Sahara-Sahel transition zones as a key area of interest for security research and policymaking (Detges, 2017; Hendrix & Salehyan, 2012; Raleigh, 2010; Raleigh & Kniveton, 2012), as well as the general interest in the expansion of the Sahara Desert, we retain these values only for African grid cells whose latitude is between 10° and 20° North. This ensures that our indicator of the transition zone only includes the Sahara-Sahel transition zone, as opposed to other deserts such as in Namibia. Thus, a given cell-month gets a value of 1 on $\textit{Sahara transition zone}_{it}$ if that cell had a predicted NDVI of 0.192 or less for 1 to 11 months in the given calendar year, and a value of 0 otherwise.

Our second independent variable, used to approximate environmental *opportunity* for conflict, is directly operationalized using monthly NDVI values, and lagged by 1 month to account for the time such effects might take translating into conflict. Accordingly, this variable, $\textit{NDVI (mean)}_{it-1}$, measures average NDVI levels within a given grid cell during the previous month, with higher values corresponding to more vegetation, as discussed above. Finally, to test our conditional hypothesis H2, we create the interaction term $\textit{Sahara transition zone}_{it}$ X $\textit{NDVI (mean)}_{it-1}$ and add it to our models alongside each constitutive term.

In addition to our key explanatory variables, we also include key controls highlighted in extant research (e.g., Koren, 2018, 2019; Linke & Ruether, 2021; von Uexkull et al., 2016). Here, we first include NTL_{it}, an annual indicator of nighttime light emissions, which approximate yearly economic output for each cell. We leverage AfroGrid's inclusion of harmonized night light data, which combines Defense Meteorological Satellite Program (DMSP) and Visible Infrared Imaging Radiometer Suite (VIIRS) data for the 2003–2018 period to create a more sensitive indicator of nighttime light emissions in remote underdeveloped areas (Li et al., 2020). We also account for annual population densities inside each grid cell from the WorldPop dataset (Tatem, 2017), also included in AfroGrid. Due to their ranges, both variables were logged prior to entering our models. Summary statistics for all variables are reported in Table A1, Appendix.

Because our battle variables can be treated as continuous, we rely on ordinary least squares (OLS) estimation as recommended in extant econometric research (e.g., Angrist & Pischke, 2008). Our model is specified as follows:

$$\begin{aligned} \boldsymbol{y}_{it} = \beta_0 + \beta_1\boldsymbol{D}_{it} + \beta_2\boldsymbol{C}_{it-1} + \beta_3\boldsymbol{D}_{it} \times \boldsymbol{C}_{it-1} + \beta_4\log\boldsymbol{N}_{it} \\ + \beta_5\log\boldsymbol{P}_{it} + \beta_6\boldsymbol{y}_{it-1} + \boldsymbol{\tau}_t + \boldsymbol{m}_t + \boldsymbol{\omega}_j + \varepsilon_i \end{aligned} \tag{1}$$

Here, $\boldsymbol{y}_{\mathbf{it}}$ is a vector denoting each respective conflict variable, and $\boldsymbol{y}_{\mathbf{it-1}}$ its lag; $\boldsymbol{D}_{\mathbf{it}}$ denotes whether a grid cell is in the Saharah-Sahel transition zone in year t, $\boldsymbol{C}_{\mathbf{it-1}}$ denotes the 1-month lag of average NDVI values for a given cell-month, and $\boldsymbol{D}_{\mathbf{it}}$ X $\mathbf{C}_{\mathbf{it-1}}$ is our interaction term. $\boldsymbol{N}_{\mathbf{it}}$ and $\boldsymbol{P}_{\mathbf{it}}$ are our controls, capturing (logged) nighttime light and population densities in a given cell during a given year; $\boldsymbol{\tau}_{\mathbf{t}}$ is the time trend; $\boldsymbol{m}_{\mathbf{t}}$ are fixed effects by month; $\boldsymbol{\omega}_{\mathbf{j}}$ are fixed effects by county, accounting for all country-level issues and confounders that are constant over time; and ε_{i} denotes grid cell-clustered standard errors.

Results

Table 1 reports the results of four OLS models corresponding to each dependent variable. The results strongly confirm the hypothesized effect of *Sahara transition zone*$_{it}$ X *NDVI (mean)*$_{it-1}$ on state- and rebel-based conflicts. The individual coefficient estimates on *Sahara transition zone*$_{it}$ are negative and statistically significant across all models, negating hypothesis H1 and suggesting that—without accounting for seasonal fluctuations in environmental security as conditioning harsh climate's impacts—Sahara-Sahel transition zones experience fewer conflict events, on average.

Importantly, the coefficient on our *Sahara transition zone*$_{it}$ X *NDVI (mean)*$_{it-1}$ interaction is positive and statistically significant (to at least the $p < 0.1$ level) across all state- and rebel-based conflict models, but not when conflict involving only non-state actors is concerned, implying that, in support of hypothesis H2, the frequency of state- and rebel-based conflicts (civil wars and insurgencies) in Sahara-Sahel transition zones increases during months of improved agricultural production. While we must examine our marginal effects visually to fully ascertain the significance of this

Table 1 Regression estimates of conflict determinants

	State (ACLED) (1)	**Rebel (ACLED) (2)**	**State (GED) (3)**	**Nonstate (GED) (4)**
Sahara transition zone$_{it}$	−0.004*** (0.001)	−0.002** (0.001)	−0.002** (0.001)	−0.001** (0.0004)
NDVI (mean)$_{it\text{-}1}$	−0.002* (0.001)	−0.00001 (0.001)	−0.0001 (0.001)	−0.001*** (0.0003)
Sahara transition zone$_{it}$ *X, NDVI (mean)*$_{it\text{-}1}$	0.009* (0.005)	0.010*** (0.003)	0.006** (0.003)	−0.002 (0.002)
DV$_{it\text{-}1}$	0.725*** (0.0005)	0.611*** (0.001)	0.685*** (0.001)	0.389*** (0.001)
Log NT (sum)$_{it}$	0.001*** (0.0001)	0.0005*** (0.0001)	0.001*** (0.0001)	0.0003*** (0.0001)
Log population$_{it}$	0.002*** (0.0002)	0.001*** (0.0001)	0.001*** (0.0001)	0.001*** (0.0001)
Log τ_t	0.002*** (0.001)	0.001 (0.0003)	0.001 (0.0004)	0.001*** (0.0002)
Constant	−0.014* (0.007)	0.001 (0.004)	−0.003 (0.004)	−0.005* (0.002)
Observations	1,947,324			
R^2	0.528	0.369	0.470	0.152
Adj. R^2	0.528	0.369	0.470	0.152

Standard errors clustered by grid cell in parentheses; logging was done in base 10; fixed effects by month and country were included in each model, although none is reported here

DV stands for "dependent variable"

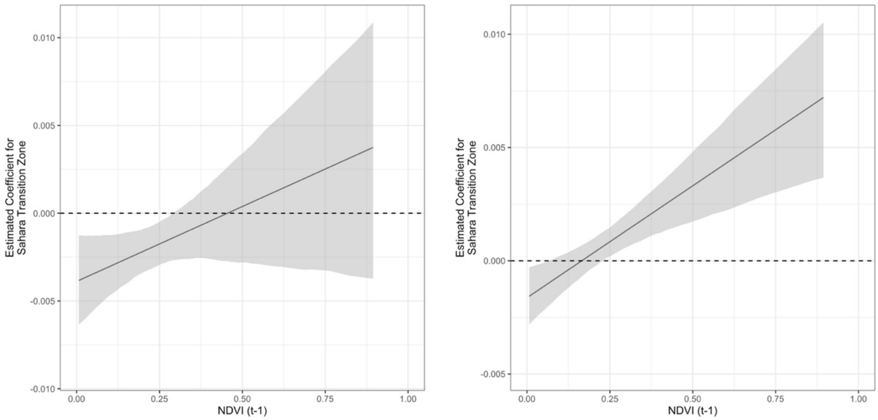
$^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

result (as we do below), this result illustrates the importance of adjusting the threat multiplier argument to seasonal variations and the impact of abundance therein.

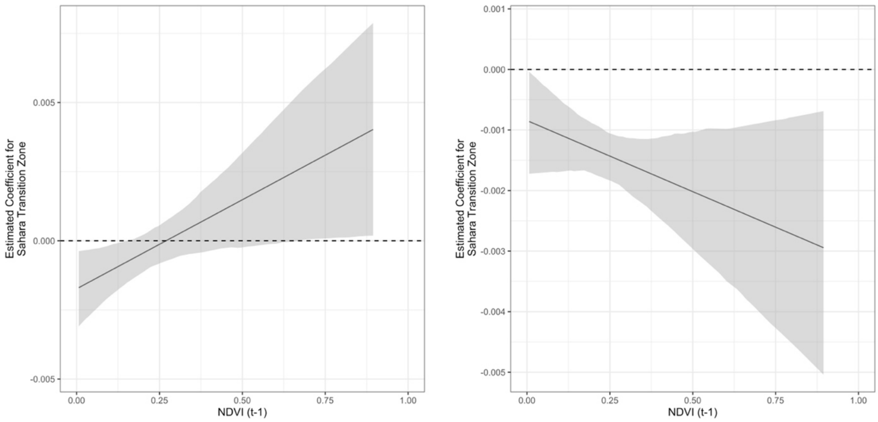
Finally, the coefficient estimates for *NDVI (mean)*$_{it-1}$ itself are negative across all models but achieve statistical significance only in models (1) and (4). These results suggest that outside of the Sahara-Sahel transition zones, lower agricultural productivity months experience more conflict, although this conclusion should be interpreted with great caution, considering the estimates are not robust across both ACLED and GED.

To further evaluate whether our interaction supports our hypothesis, we use the estimates from each model to calculate the change in *Sahara transition zone*$_{it}$'s coefficient (i.e., when the variable is changed from = 0 to = 1) on the expected number of conflicts across the range of *NDVI (mean)*$_{it-1}$ (0 ⇔ 1) over the 2003–2018 period. We plot these estimated marginal effects for each of our OLS model specifications, along with their 95% confidence intervals, in Fig. 1.

Looking at *state battles (ACLED)*, we observe that Sahara-Sahel transition zones are expected to experience, on average, a reduction of 0.004 state-led conflict incidents from the baseline in a given month when NDVI is minimum, but an increase of 0.004 incidents (which is generally the same as the baseline rate of conflict events in the sample) when productivity is at its max. Considering that the mean/baseline for our sample is 0.009 state-led conflicts per cell-month, this reflects a 91.4% increase in the number of incidents at high agricultural productivity. The statistically significant 91.4% decrease at low agricultural productivity supports our argument that willingness to fight without opportunity is unlikely to yield conflict. For *rebel battles (ACLED)*, we observe an even greater effect



State battles (ACLED) *Rebel battles (ACLED)*



State battles (GED) *Nonstate battles (GED)*

Fig. 1 Predicted change in *Sahara transition zone*$_{it}$'s coefficient as *NDVI (mean)*$_{it-1}$ is changed from minimum to maximum values

of these dynamics on attacks initiated by rebels. Here, Sahara-Sahel transition zones are expected to experience about − 0.002 less rebel-initiated conflicts than average when NDVI the previous month is at its minimum, but a 0. 007 increase in the number of such attacks when NDVI is at its max. Again, considering the mean of rebel-initiated attacks per cell-month is 0.003, this translates into a staggering increase of more than 300% in the number of these incidents. Moreover, as Fig. 1 shows, the rebel-initiated conflict case is especially in line with our expectations, where times of environmental scarcity within these adverse climate conditions areas cause a different-than-zero reduction in conflicts, while times of abundance generate a different-than-zero increase, which is directly in line with the conditional change in opportunity we hypothesized in the theory section.

For the GED-based indicators, we see that *state battles (GED)* shows a similar trend to that observed in the *rebel battles (ACLED)* case, although the confidence intervals are slightly larger. This might not be surprising considering that—in coding all fighting involving state and rebel forces regardless of the initiator—this indicator greatly overlaps with both *state battles (ACLED)* and *rebel battles (ACLED)*. Substantively, changing a cell's designation to Sahara-Sahel transition zone leads to an approximately 0.002 reduction in state-based conflict incidents when NDVI values the previous month are at zero, but to an approximately 0.004 in these incidents where NDVI is at its max. Again, considering the sample's average is 0.001 incidents per cell-month, this constitutes a total average increase of more than 140% in the number of incidents per cell-month. Finally, turning to *nonstate battles (GED)*, which had a statistically insignificant coefficient in Table 1, we find that a Sahara-Sahel transition zone location is expected to experience a reduction of about 0.001 incidents when NDVI the previous month is at 0, and a reduction of 0.003 when NDVI is at its max. Substantively, as the sample average of *nonstate battles (GED)* is 0.0013 incidents, this translates to about 150% reduction in the number of events. Overall, then, Fig. 1 provides immense support for the results from Table 1, further underscoring our theoretical claims and the importance of accounting for both willingness and opportunity when analyzing relationships between climate and state- and rebel-based conflicts.

To test the sensitivity of our results, we report and discuss a battery of robustness tests, corresponding to each specification from Table 1, in the Appendix. Briefly, these tests include (i) baseline models without controls, fixed effects, and the time trends (Table A2); (ii) models that omit the interaction term to illustrate the findings are only robust in the case of our conditional relationship (Table A3); re-estimating Table 1 using the FELM package, which relies on a different protocol to identify relationships and estimate standard errors, both (iii) with and (iv) without the interaction (Table A4); (v) re-estimating Table 1 with an interaction of country and year fixed effects to account for all country-level factors that vary by year (democracy, GDP, population, etc.); (vi) re-estimating Table 1 with an interaction between our country fixed effects and the time trend, a method that is akin to a synthetic control interpretation (Table A5); and (vii) using a count fixed effect model instead of OLS (Table A6). Most, although not all, of these sensitivity checks yield similar levels of statistical significance. Coefficient signs are also consistent with the results we report in the main text. Our results are therefore robust across these different specifications, suggesting our conditional relationship hypothesis is reasonably robust to underlying confounder and modeling concerns.

Discussion

By showing how conditions that increase environmental security and by extension agricultural productivity shape the timing of state- and rebel-based conflicts within locations subject to harsh climate, our results inform research on the climate-conflict nexus, as well as on broader climate-warfare dynamics. We control for population and state presence, so we expect that the negative coefficient on $NDVI\ (mean)_{it-1}$ is not the result of higher agricultural productivity acting by alternative pathways, e.g., via improving economic well-being or the remoteness of and lower state capacity within these areas, which could generate grievances due to other reasons, for instance due to growing inequality of because the state may not be providing effective services.

In theoretically linking environmental security with climate stress, we are also able to reconcile differing findings across studies that emphasize the impact of climate stress on conflict and research that highlights the role of agricultural resources as a conflict driver. For researchers who emphasize resource abundance (e.g.,Crost & Felter, 2020; Koren, 2018, 2019; Koren & Bagozzi, 2016; Linke & Ruether, 2021; McGuirk & Burke, 2020), the relevant incentives pertain to rapacity: the need of different armed actors to feed and support their troops, to appropriate and sell cash crops for revenue, or to prevent their rivals from accessing resources to achieve these ends. As we show, such dynamics are relevant, but they are the most accute when they happen *within the context* of harsh climate.

In addition to the theoretical significance of our findings, we also provide an important empirical extension. Here, we highlight the importance of operationalizing local climate-conflict dynamics at the monthly rather than annual levels. Given the seasonal variability of rainfall, temperature, agricultural productivity, etc., a straightforward way of identifying locations with desert-like conditions within a given month based on rainfall does not exist. Our NDVI-based indicator captures spatially and temporally disaggregated agricultural productivity, which combines human behavior with environmental systems, ensuring we capture month-to-month variation in whether human adaptation provides resilience to harsh environmental conditions.

Finally, it is important to highlight relevant scope conditions. Our findings are specific to African states and especially to the distinction of the Sahara transition zone within different countries and conflict "hotspots" across the center of the continent. Any inductive reasoning to broader patterns within other desert transition zones as well as other world regions requires additional research.

Conclusion

Our theory and results underscore the importance of considering local context. We find that, broadly, climate harsh locations may experience more conflict compared with other areas, but only when environmental security levels are high, which translates into greater agricultural resource abundance within these locations. Our 0.5-degree cell-month allows us to operationalize seasonal variations in climate and productivity across the entire African continent directly into our models, improving on past research that focuses on specific areas or uses higher levels of aggregation (e.g., at the country level), or focuses on annual as opposed to intra-annual variations.

For future research, our findings outline several trajectories. First, we show the importance of more comprehensively accounting for seasonality within climate-conflict nexus research. As more temporally and spatially disaggregated data become available, the scope of global studies can be increased, identifying more nuanced—and crucial—relationships (e.g., von Uexkull & Buhaug, 2021). Second, by focusing on willingness and opportunity dynamics and theorizing them using the conceptual terminology of climate harshness and environmental security, our theoretical framework helps link climate-conflict research to broader research on inter- and intrastate wars (e.g., Siverson & Starr, 1991). Our willingness-and-opportunity-based framework can also be extended to cover other forms of violence, such as civilian victimization (e.g., Dowd & Raleight, 2013; Koren & Bagozzi, 2017).

Third, both our theoretical and empirical frameworks highlight the importance of separating the *where* from the *when* in the analyses of climate's impact on conflict. This is important not only for researchers, but also for policymakers trying to prepare for and preempt climate change's adverse effects on violence globally. Here, we directly show that preventive and preemptive initiatives should focus on not only specific locations, but also effectively time relevant interventions to periods where conflict incentives are the most acute to achieve maximal impact.

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Data availability Upon publication, data and replication materials will be posted on the Harvard Dataverse site here: https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/LDI5TK.

Declarations

Equal authorship implied. Schon began employment at the Department of Homeland Security (DHS) after the study was originally submitted for review. This study does not reflect the views or official positions of DHS. The authors are not aware of any competing interests.

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