Bioclimatic and Access Indicators of Investor Preferences for Agricultural Land Deals in Sub-Saharan Africa

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ABSTRACT

Large scale land acquisitions, also referred to as land grab deals, are a global phenomenon often associated with neoliberalization and globalization. Land deals conducted for agricultural purposes are often driven by climate change induced food insecurity and demand for biofuels. Sub-Saharan Africa has a long history of large scale agricultural land acquisitions by foreign entities. This region is often targeted due to a lack of legal protections for local community and indigenous groups and other historical sociopolitical and economic factors, and is legitimized by neocolonial discourse from major development organizations. While these elements of agricultural land deals have been explored thoroughly in the literature, there is very little information regarding the bioclimatic and access elements investors may consider when deciding where to buy land for agroexport purposes, and particularly a lack of quantitative research. This study creates a framework for exploring investor preferences of bioclimatic and access dimensions of agricultural land deals in Sub-Saharan Africa using geospatial and statistical methods. My results indicate that in a majority of tested countries, investors seemed to considered levels of mean annual precipitation, aridity, and access in land deal location. Within these parameters, investors preferred areas with higher levels of mean annual precipitation, lower aridity, and better access, but did not consider interannual variability for a majority of countries. Additionally, I found no correlation between aridity and access for a majority of countries. This information can be used to inform more targeted policy and intervention efforts to better safeguard these types of areas from land grabs. This method can also be applied to other relevant variables and be used to explore other impacted countries in the Global South to better understand patterns of investment in order to protect these areas.

KEYWORDS

Geospatial, neoliberalism, globalization, climate change, land rights

INTRODUCTION

Large scale land acquisitions (LSLAs) are defined as land acquisitions greater than 200 hectares per deal, and are often transboundary investments that occur between any combination of governments, corporations, and non-governmental institutions. (Messerli et al. 2014). The more political term 'land grabbing' has also been used by some scholars to describe this phenomenon because of the of the often neocolonial nature of these deals, such as foreign entities buying land in the Global South to produce commodities for export, which can lead to the removal of local people from their land (Borras et al. 2012). Land grab deals also occur in secrecy with little to no transparency and participation by those who occupied and used the land prior to investment. Due to the scale and range of impacts these LSLAs have on land use and land cover change, it is important to understand the various factors that drive them (Davis et al. 2015).

Land grabbing has allowed various institutional and corporate actors to accumulate control of over 56.2 million hectares of land in Sub-Saharan Africa alone since the year 2000, and those are just the publicly reported numbers (German et al. 2013). This land rush has been driven by the need to satisfy demand for various commodities in domestic and international markets, and is a facet of increasing globalization under a capitalist, neoliberal political economy. This phenomenon has likely been driven by increasing demand for bioenergy, coupled with recent global food crises (in 2008 and 2011) and other factors (McMichael 2012) that have led to higher valuations of certain biofuels crops and perpetuated the agricultural drivers of foreign direct investment. These specific crops, like corn and soybean for example, are referred to as 'flex crops' due to their dual use for biofuel production and food for farm animals and people. The global biophysical conditions of flex crop production that impact global food security are influenced by climate change and require deeper study (Borras et al. 2012).

In addition to being exacerbated by climate change, threats of food insecurity in many countries are driven by the increase in flex crop prices, as well as increases in food demand due to population growth and dietary shifts (Müller et al. 2008). This has further contributed to LSLAs taking place for agroexport purposes (Scheidel and Sorman 2012). Such agroexport production models have led to notable land use and land cover changes, and consequently have negatively impacted the livelihoods of many local people, especially (but not solely) in the global South. Given the harmful historical relationships and inequitable power dynamics between many of the countries involved in the global land grabbing phenomenon, it has been characterized as a neo-colonialist process by several scholars (Margulis et al. 2013). The effects of this perpetuation of colonialism in the form of land grabs vary from country to country, and are dependent on a multitude of social, political, economic, and environmental factors that require more research to better understand (Borras et al. 2012).

In the case of Sub-Saharan Africa, socio-political and economic conditions have made it a popular target of many investors for agricultural land acquisitions (Baglioni and Gibbon 2013). For example, some studies estimate that up to 60% of the land in the region is communally owned (Who Owns the World's Land? 2015), making it easier for land grabbing to occur due to ambiguity in property rights, especially within the context of political instability (Allan et al. 2012, Dell'Angelo et al. 2017). These communal land plots are usually on indigenous territories and other community group lands, and follow "customary tenure systems" in which the state tends to legally own the property (Moreda 2016). The area has also been characterized by an investment practice that is in alignment with neoliberal trade policies, and is perceived to have lots of cheap labor and land that is good for farming (De Schutter 2009, German et al. 2013). For example, the World Bank has promoted the region as agriculturally underutilized, thus openly encouraging intensive commercial agricultural development (Directions in Development 2009). However, some of these land deals remain purely speculative, with no development after purchase, destabilizing the mainstream narrative of increased food production from such deals. Both speculative and developmental LSLAs have contributed to both social and environmental devastation in the region and beyond, highlighting the need for better understanding of the biophysical factors associated with land grabbing (Dell'Angelo et al. 2017).

LSLAs are also often developed in large-scale, industrialized monocultures, which have been shown to disturb the social and physical environment (Messerli et al. 2014). This type of intensive agriculture contributes greatly to climate change and also affects the immediate environment through deforestation, pollution from farming inputs, and other harmful disturbances (Dell'Angelo et al. 2017). From a sociocultural perspective, such developments displace people from their land, perpetuate regional food insecurity, disrupt land-based social relations, and generally disenfranchise less dominant social classes within local communities (Borras and Franco 2012, Borras et al. 2012). Land grab deals also exist in opposition to the fight for food and land sovereignty by rural, landless people (McMichael 2013). These forms of violence manifest in quantifiable metrics and less easily measured social, cultural, and spiritual losses that greatly impact livelihoods (Verma 2014). Therefore, understanding the biophysical aspects of these land deals in relation to social factors can allow for unique perspective into this complex phenomenon.

Researching these generally harmful land deals on a more local level can provide deeper insight into their drivers and allow for a better understanding of investor preferences (Messerli et al. 2014). Due to the fact that land deals can be agriculturally driven, assessing their local biophysical elements is relevant here as well (Scheidel and Sorman 2012, Hettig et al. 2016). For example, adequate climate conditions and access to water are necessary components of successful crop production (Davis et al. 2015). This information, coupled with our understanding of larger, global sociopolitical and biophysical drivers of investment (e.g. economic demand for flex crops), can then be used to help predict future patterns of land deals under more extreme climate change conditions. While the literature has heavily referenced the social factors that make LSLAs desirable to investors, there is still much research needed to explore the biophysical elements that investors may prefer (Dell'Angelo et al. 2017).

My objective is to determine whether statistically significant relationships exist between biophysical factors and investor preferences in agricultural land grab deals in Sub-Saharan Africa. Specifically, I ask:

1. What is the associative relationship between climate characteristics (specifically mean annual precipitation, interannual variability, and aridity) and land deals? Are these values significant in determining investor preferences of land deals? In what ways?
2. What is the proximity of land deals to access points, such as cities with high population density? Are these proximities to access points significantly different from those of areas without land deals?

To address these questions, I collected land deal location data for Sub-Saharan Africa using information recorded in the online Land Matrix database (The Land Matrix 2018).

History and context of land grabbing

Land grabbing has been occurring for centuries, and primarily involves Western powers controlling land and resources in the global South under a set of unethical conditions, such as through imperialism and colonialism which operate as extractive processes (Margulis et al. 2013).

This is clear in the well cited World-System theory, which explains this process in terms of core countries exploiting resources in periphery countries, imposing economic control, and shaping social, political and cultural structures and processes (Chirot and Hall 1982). Additionally, colonial frameworks of Euro (white) supremacy and patriarchy are manifest in violence such as racism, sexism, queerphobia, and other forms of xenophobia. The periphery is constructed as “other” because it is seen as the site of deviation from Eurocentric norms, which further contributes to justifying violence against it. It is through this vicious cycle of justified entitlement that land grabbing became a common fixture in colonial relations (Williams and Chrisman 1993). In an ecological sense, this causes the unbalanced movement of natural resources from periphery to core countries, and negatively impacts the peripheries’ related biogeochemical cycles (Hornborg 2011). Today, land grabs reflect and perpetuate historically constructed power inequities between countries (Carmody and Taylor 2016), but the drivers, levels of scale, and the rate of acquisitions are different (Margulis et al. 2013). This now occurs in an arguably less explicit form some scholars have termed “ecocolonization” (Carmody and Taylor 2016).

Modern day land grabbing is characterized by foreign entities (such as nations, non-governmental organizations, or corporations) buying land in other, usually lower income nations in order to use it for their home country’s benefit (Borras et al. 2012). This is often associated with the displacement and disenfranchisement of local communities, which are rarely involved with decision-making and often do not benefit from land deals (Davis et al. 2015). Under ecolonialism, these local communities become “subjects rather than citizens” due to the denial of their rights to the land through the country’s assertion of control over it as a means of accumulating more state-controlled capital. This leads to dispossession on a large scale and can impede local communities’ rights to self-determination and autonomy over traditionally occupied land (Carmody and Taylor 2016). The globalization and related neoliberalization of international relations that has been increasing since the 1980’s has contributed to these shifts. Since 2008 in particular, land grabbing has increased significantly due to changes in global political economic structures, as well as real and perceived insecurities caused by climate change, namely food and energy scarcity (McMichael 2012).

Simply put, ‘neoliberalism’ is a political philosophy that advocates for various sectors, including the ecological, to be regulated by a free market (Büscher et al. 2012). Its advocates argue that the market is better able to allocate and regulate scarce natural resources than a ‘command

and control' model in which governments set more rigid policies and regulations surrounding conservation. (McAfee and Shapiro 2010). The manifestation of this ideology transforms relationships to the environment so that the capitalist market, which relies on continued consumption, regulates environmental protection. Critics of this model argue that by relying on the market, historical (and contemporary) systemic and structural inequities remain unaddressed, and these inequities are considered main drivers of global environmental degradation (Igoe and Brockington 2007). The term 'globalization' in this context can be characterized by the flow of different commodities, labor, and ideas across various spatial boundaries through various different modes and relations of power. Additionally, the interconnectedness of global political, sociocultural, technological, and economic forces today are manifest in the movement of agricultural goods and related land rights across space through various modes of governance, including by the market (Margulis et al. 2013).

Therefore, neoliberalism is inherently linked to global capitalism, where aspects of the market are viewed as the solution to environmental problems created by other aspects of the market. This creates a self-perpetuating cycle that ultimately leads to the degradation and commodification of nature while simultaneously expanding the capitalist market in the world economy (Büscher et al. 2012). For many investors, whether they be crop importing governments or large for-profit corporations, agricultural land has become a highly valuable form of capital that has increased in value as global climate related crises occur (Zoomers 2010).

Drawing on a political ecology approach, Anseeuw (2013) identifies four structural causes of land grabbing: "the financialisation and corporatisation of agriculture; the concentration and dualisation processes of the sector; speculation and its interface with the engagement of foreign powers; and, finally, the proletarisation of the African agricultural masses." The first two drivers refer to shifts in the agricultural sector that favor larger, industrialized operations over smaller farmers due to the high demand for cheaper agricultural goods that can only be economically feasible through integration and mergers to achieve economies of scale. The third cause refers to the globalization and neoliberalization of the economy and the role of foreign investors in influencing local governance and autonomy. The final driver refers to the sociocultural, political, and economic shifts in the status of agricultural communities to a more disenfranchised position. These globalized phenomena and their more tangible effects provide a useful framework for understanding contemporary land grabbing, including new dynamics that have come about between various nations.

For example, land grabbing no longer fits explicitly into a global North - global South paradigm, and countries from the global South are engaging in large scale land acquisitions in other countries from the region. There are instances of the same country being both the land grabber and simultaneously having its own land grabbed by another entity, such as a nation or corporation. Additionally, climate change and its effects on agriculture, namely increased droughts, changes in temperature and precipitation, increases in frequency and intensity of natural disasters, migration of flora and fauna, biodiversity loss, and much more are considered more global drivers of land grabbing (Margulis et al. 2013, Turral et al. 2011). In Sub-Saharan Africa, various more local drivers of land grabbing have been associated with such climatic threats. These climatic drivers could potentially be influencing investors' preferences in the region, including the more biophysical aspects of where any one land deal might take place (Messerli et al. 2014).

The Sub-Saharan case

Sub-Saharan Africa is a target for many land grab deals due to perceptions surrounding availability of land in the region, constructed by both prominent modern institutions and colonial-era myths. Imperialist philosophy and blatant anti-Blackness, seen most often in oppressive religious doctrine, discriminatory laws, and racist 'scientific' studies, were present throughout colonial times, and still today. These ideologies perpetuated the perception of African land being 'for the taking' due to ideas such as the divine right of Europeans to use land to its 'fullest potential' (Morgensen 2011). Additionally, the political geography theory of environmental determinism, which argues that physical conditions like climate and geography determine societies' characteristics and cultural development, justified the idea of white supremacy, as well as presented imperialism as part of the 'natural' order because inhabitants of tropical regions were perceived as lesser than and incapable of governing themselves and their resources (Gilmartin 2009, Painter and Jeffrey 2009). It is important to note that in Africa, land is often collectively owned by rural communities and functions as a key asset and integral part of indigenous land stewardship (Anseeuw 2013). The conception that these lands are not being used, along with the other ideas mentioned above, were drawn on to justify colonization in the Sub-Saharan region and other places in the global South during the late 19th century through the mid-20th century.

While these foundational myths have changed over time, their message of outside intervention to maximize potential remains the same today. Instead of being touted by Western imperial states, we now see prominent (usually Western) institutions such as the World Bank, International Monetary Fund (IMF), and United Nations agencies reframing these ideas for the sake of the so called 'common good', and to integrate conservation and development efforts. This is typically found in language surrounding sustainable development, where terms such as 'underdeveloped', 'Third-World', and 'traditional' are steeped in colonial power dynamics that then lay the foundation for the discourse of development. This is especially apparent in the ambiguity of the term 'sustainability' itself, and how it is informed by colonial logics that can serve to disempower some communities by imposing (typically Western) definitions and ideology onto so called 'developing' nations (Banerjee 2003). One way this manifests is through sustainable development ventures like 'payments for ecosystem services (PES)' programs, where ecosystem services become commodified and tradable, and "binary categories of nature and society" become simultaneously imposed on cultures where such a divide may not exist (McAfee and Shapiro 2010). This is a clear example of how sustainable development discourse operates from the dominant neoliberal economic paradigm, and becomes institutionalized through the "operation of international finance capital" in the form of large Western development organizations (Banerjee 2003). Furthermore, international organizations such as the World Bank and the IMF have been known to encourage outside investment in African land for the purposes of 'optimizing its potential'. This is typically in the context of increasing crop production to combat food insecurity, and climate change is often solely blamed for exacerbating this condition, rather than the socio-political or economic conditions that govern our global food system (De Schutter 2009, Directions in Development 2009). This logic surrounding sustainable development is fundamental to the perpetuation of contemporary land grabbing.

Large-scale land acquisition for the purpose of conservation is also common, and is informed by the myth that local people are not capable of managing their own lands and can be better helped by outside efforts. These efforts are typically intertwined with development initiatives and can be useful by providing monetary, logistical, and other resources to improve local people's livelihoods. However, it is important to note that intervention for conservation and development purposes often walks a fine line, where seemingly good intentions can become the means through which local communities lose sovereignty over their land and cultural practices. Usually poverty and increasing urbanization are blamed for environmental devastation in countries of the global South, but many analyses lack nuance and fail to capture the historical and contemporary harm caused by Western powers that has lead to their current state (Singh and Houtum 2002). While many contemporary land deals in the Sub-Saharan region are for agricultural and energy purposes, and are encouraged by large international development organizations, the literature on this topic reveals how conversation around land grabbing has changed over time.

Themes in early literature about land grabbing

Early literature (1990-2006) on land grabbing and large-scale land acquisitions focused on the state of countries restructuring their societies while being influenced by global affairs. For example, Mozambique started to recover from civil war around the late-1990s, as more than half of its total land area was bought by commercial enterprises taking advantage of political and economic instability that made land grabbing easier for outside investors. This story is similar to those in other African countries affected by war, and shows how wartime conditions, as well as policies from the colonial and post-independence period, make it difficult to determine rights and ownership to land because of the many competing parties involved (Myers 1994). In addition, the corruption of local governments and politics that contribute to ambiguity of and loss of rights to locally tenured and occupied land were also emphasized in the literature. For example, during the Northern Ugandan war (1986-1998), the Acholi peasantry faced much violence from both the Lord's Resistance Army (LRA) and the Ugandan military (UPDF). Many of the Acholi people were displaced into camps, and this was perceived as a means to remove them from their land so it could be taken by the government and sold to investors (Branch 2005). Moreover, land grabs tend to be framed as "forced" or "illegal" throughout the literature during this time, as rampant political and economic instability created conditions in which land could be more easily expropriated and grabbed.

Beginning in the 1980s, community-based natural resource management systems were promoted by development and conservation organizations, requiring locals to share their land with commercial institutions and agencies, such as the Food and Agriculture Organization of the United

Nations (FAO) and the World Wildlife Fund (WWF). There are instances of success where conservation is achieved to some degree and local communities benefit from these initiatives. However, such schemes can also result in loss of control over land by local people, and in South Africa especially this "collide[s] with a bitter history of white colonization and land grabbing (Hughes 2002)." In this sense, land grabbing was often understood as a (neo)colonial process in the literature during this time. While early literature has focused on effects and drivers within countries, more contemporary literature emphasizes the role of increasing globalization and inter-country relations instead.

Themes in contemporary literature on land grabbing

Since 2007, literature on land grabbing has focused on the role of national and international investors, and the specific global socio-political and economic drivers of large-scale land acquisitions. Researchers have emphasized the diversity of reasons for land acquisitions, ranging from extractive processes such as for food, forestry, or industry to seemingly less harmful practices such as overseas conservation, tourism, and renewable energy production (The Land Matrix 2018). While these may initially appear to be diverse factors, the discourse around land deals often cites climate change as an umbrella driver of all of these different types of investments. Specifically, climate change is predicted to exacerbate declines in agricultural productivity in many places, and this, coupled with increasing urban populations and dietary shifts, has already started to contribute to global food insecurity. This was evident in the global food crises in 2008 and 2012, during which climatic factors were central to rising agricultural prices that left many food insecure (McMichael 2012).

These factors, among others, have led many countries to look outward to satisfy increasing demand for goods in the face of decreased security, and this has been encouraged by neoliberal policies that promote participation in the global economy, making it easier for countries to invest in land in other places to meet their needs. The literature focuses on the ways large transnational corporations and international institutions interact with each other when engaging with these issues (Borras et al. 2012, McMichael 2012, Margulis et al. 2013). Even large-scale land acquisitions for seemingly beneficial purposes such as conservation often end up displacing and otherwise harming local populations (Singh and Houtum 2002). For example, the United Nations' REDD Program, which is meant to preserve and protect the Amazon rainforest from deforestation, has been criticized by some scholars for forcibly displacing indigenous Amazonian communities and disrupting their livelihoods (Van Dam 2011). Again, the myth of peoples of the global South being unable to manage their own resources is perpetuated in familiar yet distinct ways. Given the current literature's focus on these more globalized factors, I have chosen to focus on investor preferences within agricultural land deals by taking a broad spatio-temporal approach.

Methodology

My methodology is rooted in the idea that many contemporary land deals are agriculturally driven due to food and energy insecurity, and therefore reflect the need for certain biophysical conditions to exist in areas where production is desired to take place by investors. The recent literature on the topic of large-scale land acquisitions has taken a similar broad-scale approach, looking at the widely spatial and temporal conditions of this phenomenon (Anseeuw 2013, Messerli et al. 2014). Additionally, due to the highly globalized nature of land grabbing, this type of approach is helpful in understanding the larger changes that have occurred over time, and allows for certain patterns of investment to become more clear and visible when put into a historical context. Specifically, I used the open-source database, The Land Matrix, as a source of knowledge about land deal locations and purpose of investment. Research on the various effects of large-scale land deals (land productivity, deforestation, displacement of people, etc.) has also made use of this and other similar databases for information about these acquisitions (Messerli et al. 2014).

I selected the Sub-Saharan Africa due to the high number of land deals that have taken place there, its diverse colonial history, and its diverse climate. These elements are similar to other global South countries, so the results of this study can be more easily extrapolated to them. Land deals in this geographically large region also tend to be secretive and scarcely reported, which makes taking a broader scale approach more appropriate due to lack of finer scaled, detailed information (Messerli et al. 2014). In addition, the frequency of climate change related literature on this region (and in general) has greatly increased in recent years. Discourse about land grabbing in relation to climate change has also begun to frequently arise (McMichael 2012).

In my study, I defined land deals as large scale land acquisitions where negotiations on deals have concluded, according to what is reported in The Land Matrix database. This ensures that regardless of whether or not the actual investment took place, the interest and even intention to invest was present. I used bioclimatic data from the 2001 to 2017 period to account for the conditions that were present during the global food crises which were largely responsible for the more contemporary increase in land grabbing. I examined distance to densely populated areas as a proxy for access to major roadways, ports, and other means of transporting agricultural goods. As described above, agroexport is an extremely common model for agricultural land grabbing, and this model requires that goods be exported as efficiently as possible out of the country (Ouma et al. 2013). This would suggest access as an important factor when considering investment, and has also lacked substantial exploration in related research. Overall, there is still a lack of quantitative studies in this area, so my research on access and biophysical (including climate characteristics) aspects of large-scale land acquisitions aims to add more relevant information to this more contemporary theme in the literature.

METHODS

Study system description

My study site comprised 24 Sub-Saharan African countries where agricultural land deals have been reported in the Land Matrix database as having negotiations concluded, and where the number of deals in each country is greater than 3 (The Land Matrix 2018). The 24 countries are Ethiopia, Burkina Faso*, South Africa, Mozambique, Zimbabwe, Central African Republic*, Kenya, Liberia, Malawi, Mali, Uganda, Angola, Benin*, Cameroon, Ghana, Nigeria, South Sudan, Senegal, Sierra Leone, Swaziland*, Tanzania, Gabon*, Guinea*, and Rwanda. Countries with under 10 land deals with be marked with an asterisk (*) throughout this paper to indicate a lack of statistical viability given the small sample size (see Appendix A for complete table of land deals by country). The data for these countries was downloaded on March 25th, 2019 from The Land Matrix website (The Land Matrix 2018).

Data collection and transformation

I downloaded georeferenced data on land deals from the Land Matrix database (https://landmatrix.org/en/) (The Land Matrix 2018). I inputted the data into ArcGIS and R where I defined XY coordinate points to longitude and latitude values based on a standard Coordinate Reference System, namely WGS84 or EPSG: 4326. I assigned a projection and datum to all of the data based on a standard Projected Coordinate System, namely WGS84/World Mercator or EPSG: 3395. Coordinates of land deals were not exact, as precise data is unavailable and many of these land deals were referenced to the nearest town, city, or other known location by the entity that reported them.

I then downloaded the data layers for other features I used in my analysis and inputted them to view in ArcGIS and to manipulate in R. I downloaded vector data of country boundaries from an ArcGIS database (https://www.arcgis.com) (Global country boundaries 2016). This shapefile did not include South Sudan as separate from Sudan, so this country boundary was downloaded from The Humanitarian Data Exchange database (https://data.humdata.org) (Humanitarian Data Exchange 2018). I downloaded high resolution gridded time series climatological data (CRU TS v4.02) from the Climatic Research Unit database in the form of Network Common Data Form (netCDF) files dating from 2001 to 2017 for different climate variables (http://www.cru.uea.ac.uk/) (University of East Anglia Climatic Research Unit 2019). Specifically, I downloaded netCDF files of global mean annual precipitation (MAP) in mm/month and netCDF files of global potential evapotranspiration (PET) in mm/day. The resolution of both datasets was 0.5°. I downloaded data on road access for 2015 from The Malaria Atlas Project database, which was a raster file comprised of data on distance to the nearest 'densely-populated area' measured in land-based travel time by minutes (https://map.ox.ac.uk/) (Weiss et al. 2018). Here, a 'densely-populated area' is defined as "contiguous areas with 1,500 or more inhabitants per square kilometer or a majority of built-up land cover types coincident with a population center of at least 50,000 inhabitants" (Weiss et al. 2018). The resolution of this dataset is 1x1 km. I then assigned a projection and datum of WGS84 or EPSG: 3395 to all of this data, matching that of the land deal point data.

Data preparation

I installed the 'ggmap', 'ggplot2', 'rgdal', 'rgeos', 'sp', 'tmap', 'cruts', 'sf', 'plyr', 'classInt', and 'raster' packages in R (Bivand and Rundel 2018, Bivand 2019, Bivand et al. 2013, Bivand et al. 2018, Hijmans 2018, Kahle and Wickham 2013, Pebesma 2018, Pebesma and Bivand 2005, Taylor 2018, Tennekes 2018, Wickham 2011, Wickham 2016). I prepared my mean annual precipitation data by converting netCDF files into raster files using the 'cruts' package. I then averaged monthly MAP data into yearly data, and then averaged that yearly MAP data into a single raster file consisting of a 15 year average of mean annual precipitation from 2001 to 2017. I prepared data on interannual variability of precipitation (unitless index) by dividing the standard deviation of the single 15 year averaged MAP file by the the original 15 year averaged MAP file using raster math and the 'raster' package. I then prepared my aridity data by converting the PET netCDF files to raster data using the 'cruts' package and converting the mm/day values to mm/month values. I then averaged the data similarly to that of the MAP data to produce a single raster file of the 15 year average of PET in mm/month from 2001 to 2017. To get a single raster file of the 15 year average of aridity (unitless index) from 2001 to 2017, I divided the 15 year averaged MAP file by the 15 year averaged PET file. I then clipped each of these single raster file variables (MAP, interannual variability of precipitation, aridity, and access) to the continent of Africa for faster processing in R.

Null and test point generation

To generate null points with which to compare my known land deal or test points, I randomly selected points from known agricultural areas within each country. Specifically, in R, I combined data on known pastures and croplands as of 2000 from the EarthStat database to generate one raster file of global agricultural zones (http://www.earthstat.org/) (Ramankutty et al. 2008). I cropped this raster file to the boundary of each of the studied countries, and then converted each cropped file to a vector file. I used the 'spsample' function from the 'sp' package to randomly generate 100 and then 1000 null test points in each country from within these known agricultural zones. Points were generated within each country and subsequent analyses were conducted on a country by country basis in an attempt to hold other social, legal, and political variables constant.

I then circularly buffered each land deal and each null point by 200 hectares, as this is the minimum size needed for a land deal to be classified as a "large-scale land acquisition" (Messerli et al. 2014). While exact sizes of some land deals were known, many were unknown or lacked precision, so a conservative estimate of the minimum value of 200 ha was used for all land deals and null points.

Generation of variable distributions

In order to generate the distribution of values for each climate and access variable with respect to the spatial distributions of land deal points and null points, I used a geospatial overlay method. For each variable (MAP, interannual variability of precipitation, aridity, and access), I clipped the raster layer to the boundary of each country. I then overlaid the buffered land deal points for that country on top of this variable layer and extracted the grid cell values beneath these points to generate a distribution of values for each variable. Because multiple raster cell values corresponded to a single buffered land deal site in space, these values were averaged to output a single mean value for each land deal point. This method was repeated for all 24 countries for all 4 variables for each set of land deal points. The same process was repeated with 100 randomly generated null points, and then again with 1000 randomly generated null points to get different sets of value distributions for each variable for each country. In total, there were 3 sets of 4 variable value distributions for 24 countries, which can be conceptualized in the form of 288 histograms.

Statistical significance analyses

I compared the 4 variable value distributions for land deal points with the 4 variable value distributions for each set of 100 and 1000 null points for each country to test for a significant difference between them. I used two different statistical tests in R to do so, namely a non-parametric t-test in the form of a Mann-Whitney U test (or Wilcoxon rank sum test), as well as a Kolmogorov–Smirnov (K-S) test. I recorded whether the results were statistically significant or insignificant for both the K-S test and the Mann-Whitney U test for each climate and access variable by country for each set of 100 and 1000 null points as compared to the land deal points. Because the comparison between land deal points and 1000 generated null points seemed to result in approximately the same level of significance across all 4 variables in total with the comparison between land deal points and 100 generated null points, I used the former in my subsequent analysis. Using the distributions (in the form of histograms) of the values of the 4 variables generated from the 1000 null points as well as the land deal sites, I compared the means of each histogram to see which mean value was greater for each variable for each country, values generated from the land deal distributions or the null distributions.

Correlation between variables

In order to determine how the variables of aridity and access related with each other based on the presence of land deal sites, I used a Spearman rank correlation test in R. The results, namely the p-value and the rho (ρ) value, were evaluated on a country by country basis to assess the significance and type of correlation, respectively.

RESULTS

Climate and access characteristics

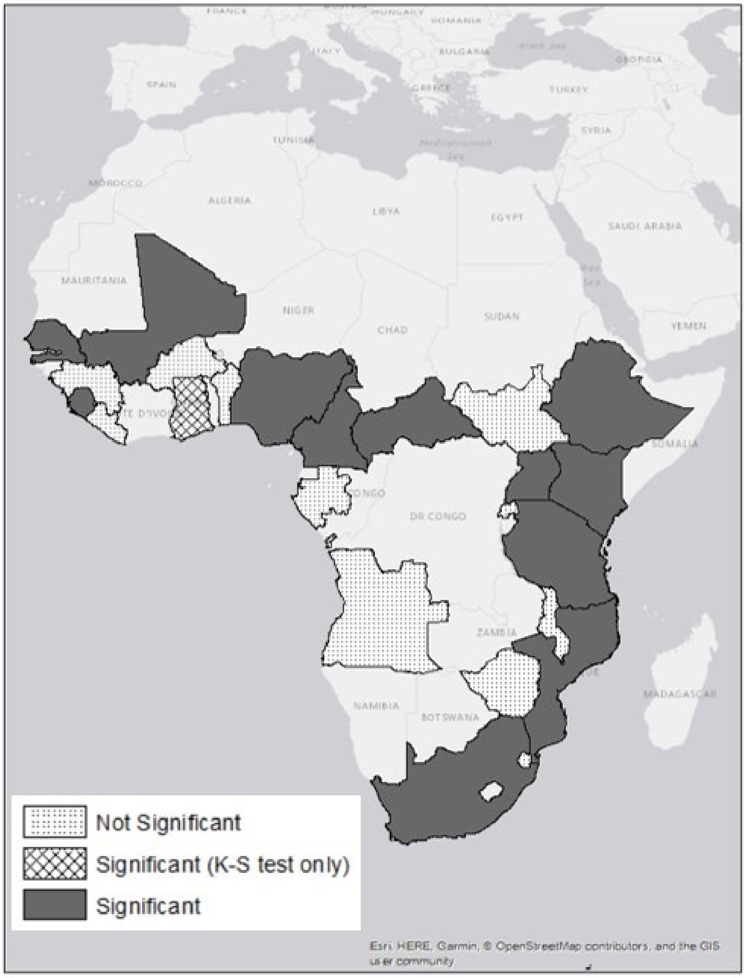
I found that majority of the 24 studied countries did not show significantly different distributions between land deal points and null points for the climatic variable of interannual variability of precipitation across all of the tests. For the access variable, a majority of countries had statistically significant differences in their land deal point and null point distributions across all tests. For significant differences for the variables of mean annual precipitation and aridity, the results varied slightly more across the two different statistical tests and the quantity (either 100 or 1000) of compared null points (Table 1). Levels of significance for all tested variables were based off of p-values, where a p-value of less than 0.05 indicates a rejection of the null hypothesis and indicates statistical significance.

Table 1. Number and percentage of countries where each variable was found to be significant for each variation of Mann-Whitney U tests and K-S tests. I generated histograms for each country for each climate and access variable to see the frequency distribution of land deal points as compared to null points.

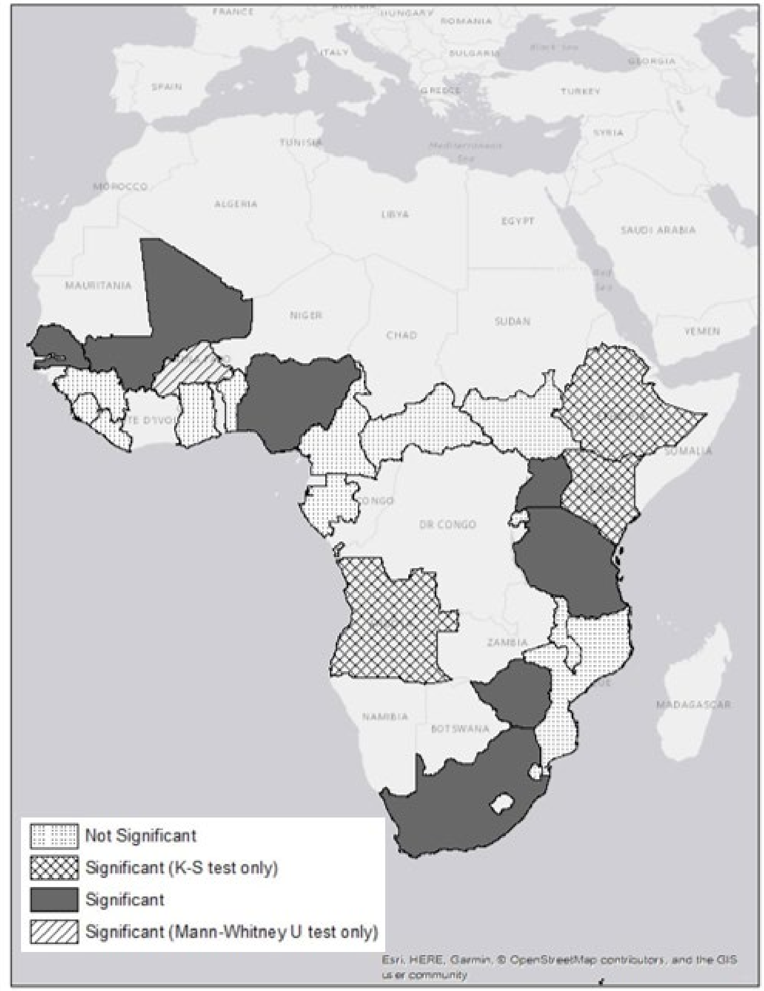
Variable	**Countries with significance (Mann-Whitney U test and K-S test), 100 nulls**	**Countries with significance (Mann-Whitney U test and K-S test), 1000 nulls**	**Countries with significance (Mann-Whitney U test only), 100 nulls**	**Countries with significance (Mann-Whitney U test only), 1000 nulls**	**Countries with significance (K-S test only), 100 nulls**	**Countries with significance (K-S test only), 1000 nulls**
Mean Annual Precipitation	10 (~42%)	12 (50%)	2 (~8%)	0 (0%)	0 (0%)	1 (~4%)
Interannual Variability of Precipitation	6 (25%)	7 (~29%)	2 (~8%)	1 (~4%)	1 (~4%)	3 (~13%)
Aridity	12 (50%)	14 (~58%)	1 (~4%)	2 (~0.08)	2 (~8%)	0 (0%)
Access	18 (75%)	16 (~67%)	1 (~4%)	3 (~13%)	0 (0%)	0 (0%)

Many countries along the eastern coast of Sub-Saharan Africa showed significance for the variables of Mean Annual Precipitation, Aridity, and Access. There appears to be similarity in significance between the variables of Mean Annual Precipitation and Aridity across all of the countries. Some countries, particularly the ones that seem to be relatively smaller in area, show a lack of significance across most or all of the tested variables (Figure 1 and Appendix B).

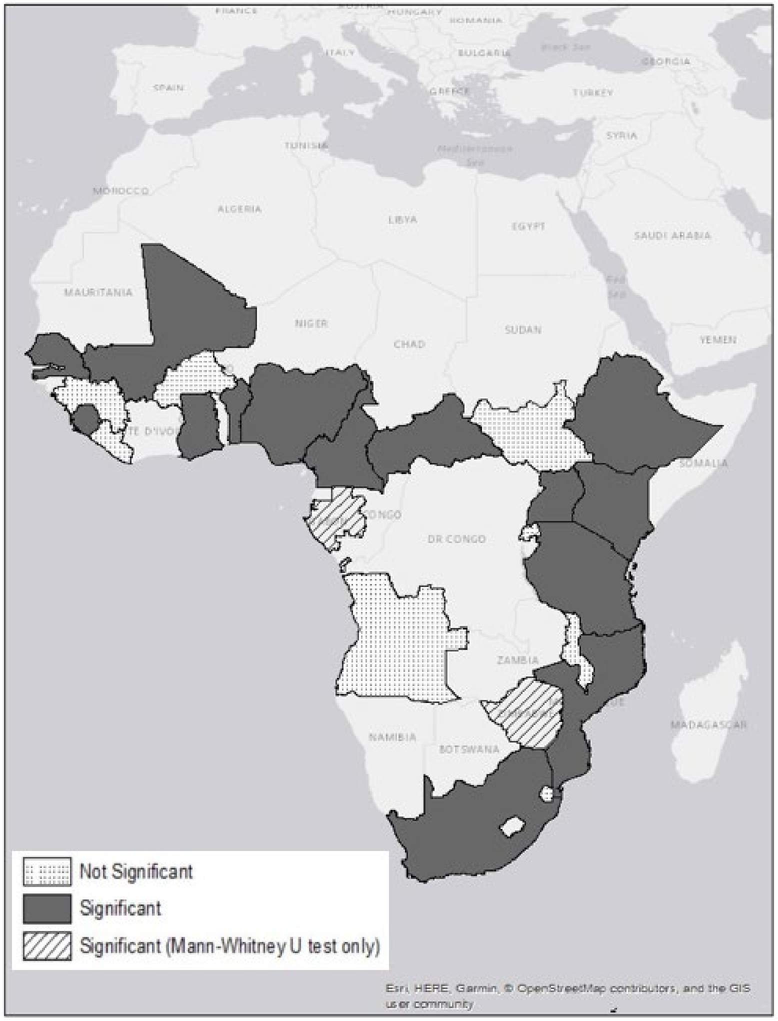
Mean Annual Precipitation



Interannual Variability of Precipitation



Aridity



Access

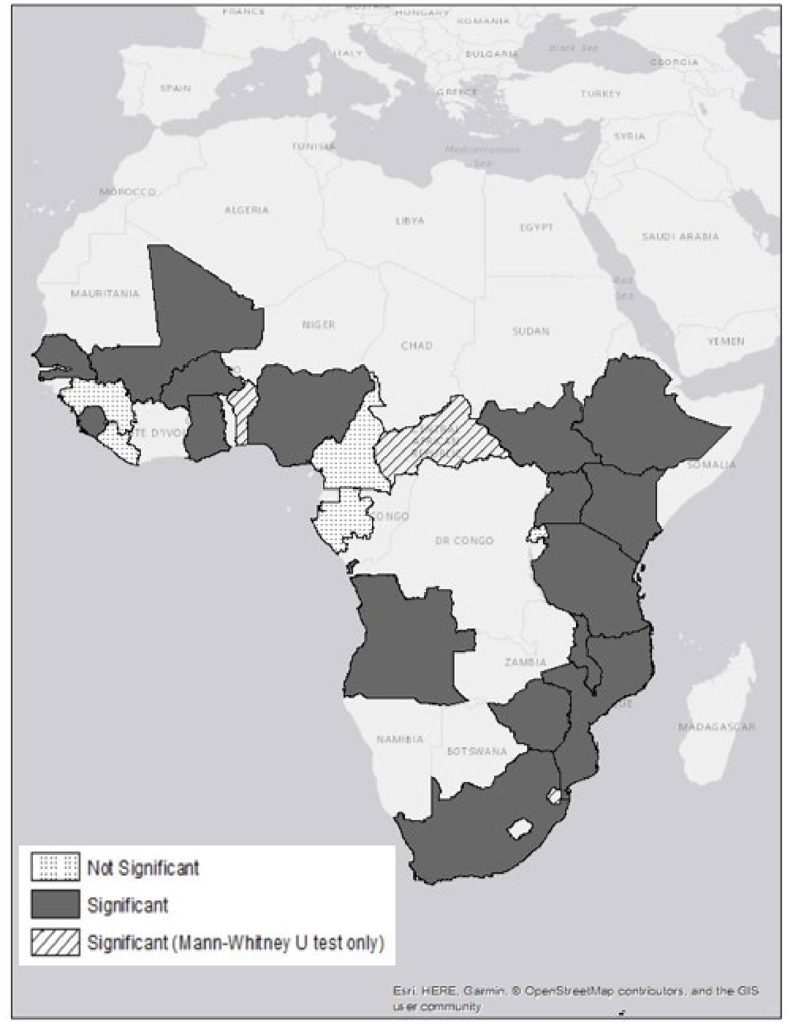


Figure 1. Results of statistical tests in each country using the 1000 null point generation in comparison to land deal sites. I conducted both Mann-Whitney U tests and K-S tests for each variable for each country.

I compared the mean values of land deal point and 1000 null point distributions for each variable for each country to measure the direction of skew. For a majority of countries, land deal points seemed to lie in areas with higher mean annual precipitation more so than null points. For a majority of countries, land deal points seemed to lie in areas with lower interannual variability of precipitation more so than null points. For a majority of countries, land deal points seemed to lie in areas with higher aridity index values more so than null points, where higher aridity index values indicate less arid regions. For a majority of countries, land deal points seemed to lie in areas with lower access values more so than null points, where lower access values indicate shorter travel-times (see Appendix C).

Correlations between variables

The results of the Spearman rank correlation test, which was based on the presence of land deal sites, indicated that a majority of countries (75%) had no statistically significant correlation of any kind between the variables of aridity and access. For Liberia (ρ= -0.4920867, p-val= 0.0049), Mali (ρ= -0.4985334, p-val= 0.0112), Cameroon (ρ= -0.4261557, p-val= 0.05406), and Swaziland (ρ= 0.05406, p-val= 0.0022), a significant negative correlation was found between the two variables, as hypothesized. There were only 2 instances of statistically significant positive correlation between the variables of access and aridity among the countries (see Appendix D).

DISCUSSION

Land grabbing is a global phenomenon that has increased in recent decades, mainly due to shifting dynamics in the realms of international relations and climate change. Specifically, the global economy has shifted towards neoliberal policies and increased globalization, and climate change has been exacerbating food insecurity and natural resource conflicts (Margulis et al. 2013). There is currently a lack of quantitative research exploring the relationship between the biophysical and access aspects of areas targeted for land deals, and how these influence where exactly investors choose to purchase land. The results of my quantitative geospatial study shed light on investor preferences in agricultural land deals, particularly in regard to the biophysical and accessibility elements, in the Sub-Saharan Africa region. The results of this study can be used to better characterize different factors that may influence whether or not a specific area is ideal for agricultural investment. This information can then be used to inform more targeted policy and land rights laws to better protect this region, and areas like it, from land grabbing.

Climate change, food security, and renewable energy

The effects of climate change have been shown to cause declines in agricultural productivity, potentially disrupting entire food systems at all levels, and with it, related sociocultural, political, and economic aspects of human livelihoods intimately connected to food. This continues to lead many countries and regions to become concerned about their food security, especially as the effects of global warming worsen (McMichael 2012). While all areas will eventually be impacted by this, there are areas that are more vulnerable than others, namely countries already food insecure or at risk of food insecurity (Nelson et al. 2016).

Climate change driven conflicts over natural resources, including arable land and water, have already been occurring and are only projected to increase, especially in regions that are already vulnerable. Countries and regions may be considered vulnerable for a number of reasons, ranging from the nature of their physical environment, such as limited agricultural potential, to political instability (internally or externally instigated), to historical factors that have influenced their current conditions, like colonization (Nelson et al. 2016). The need to preserve food security has been identified as a top priority for many nations, and has been identified as a driver of land grabbing for the purposes of agricultural production (McMichael 2012).

Another major driver of agricultural land grabbing is the increase in demand for renewable energy. The effects of climate change and related discourse have encouraged many to move away from fossil fuel use and invest in more sustainable, 'cleaner' energy. One form of this more 'green' energy has particularly piqued the interest of many investors: biofuels (McMichael 2012). Biofuels rely on the cultivation of specific crops that are used in the fuel production process, and these crops are typically referred to as 'flex crops' because they can either be consumed for food or used to make biofuels. These crops are tend to be more water intensive, and include things like soybean, corn, rapeseed, sugarcane, and wheat (Borras et al. 2012). In the recent past, increases in the value of flex crops in the international market have led to more growth of these crops for biofuel purposes rather than for food. This diversion of resources within agricultural production towards fuel production rather than for food has caused spikes in global hunger and has contributed to food insecurity. However, this increase in value has also lead to an increase in investors purchasing land through transboundary deals to grow these commodities (Zoomers 2010).

Because climate change on a broad scale is a driver of these investments for agricultural lands specifically, climate is also a key factor in understanding more local level effects (Cotula et al. 2011, Messerli et al. 2014). My study on the biophysical characterization of important variables with respect to agricultural production are helpful in understanding this factor (Scheidel and Sorman 2012, Hettig et al. 2016). The results of my study indicated that for half or almost half of the tested countries, investors seemed to consider mean annual precipitation as a significant factor in determining the location of a land deal. Within this, there seemed to also be a majority preference for areas with relatively higher levels of precipitation within the country itself. Because having ample levels of precipitation is necessary for agricultural crop production, and especially for a lot of flex crop production, this study confirms that areas with higher precipitation are potentially being targeted for such land deals in comparison with lower rainfall areas in the Sub-Saharan Africa region.

This is similar to the results of my research on the climate variable of aridity, which demonstrates that investors seemed to consider the aridity of an area as a significant factor when determining land deal location in half or over half of the tested countries. Within this, there also seemed to be a majority preference for areas that were higher on the aridity index, indicating that they were relatively less arid and more humid. Aridity is also an important bioclimatic factor to consider during agricultural production, where hyper-arid or arid areas are typically not ideal for the growth of many food or flex crops (Davis et al. 2015). These results help confirm the potential for the targeting of lesser arid areas by investors for agricultural land deal purposes in the region.

I also tested the interannual variability of precipitation at each site to differentiate between areas with drastic year to year variability from those with more consistent levels. In addition to being a temporal element, this can also be considered spatially, where areas within a country (depending on its size) could see differences in the interannual variability of precipitation. I considered this variable as relevant to agricultural production because it has been shown to influence the intra-annual seasonality of an area, as well as influence levels of Net Primary Production and other biogeochemical processes (Fatichi 2012). These are all factors that can influence the growth of plants and therefore an area's capacity to be more naturally agriculturally productive, where lower levels of variability would usually be preferred. This is due to less chances of extreme weather conditions such as droughts or floods, which would make for more reliable hydrological conditions, which are typically better for growing crops (Davis et al. 2015). However, the results of my study on this variable indicated that investors do not tend to consider it as a significant factor when determining the location of an agricultural land deal for a majority of the tested countries. The reason for this is difficult to conclude, as a variety of confounding climatic conditions could be at play, or this variable could simply just not be considered in the same way as the others.

Agroexport and access

Due to the fact that these land deals are agriculturally driven, namely for food security or biofuels purposes, financing typically come from foreign investors wanting to utilize crops for their home country or to sell elsewhere. This explains why many agricultural land deals result in the implementation of agroexport models, which are typically based on monoculture crop production for export (Scheidel and Sorman 2012). In order for agroexport to occur in a logistically feasible manner (in terms of both time and economics), it needs to be relatively easy to transport goods. This makes distance to high density areas where there are more options for access to transportation modes a key factor.

The results of my study on the variable of access confirm this idea, because investors seemed to consider access as a significant factor in the location of a land deal for more than half of the countries tested. Within this, a majority of countries had land deals that mostly seemed to take place in areas with relatively shorter distances to high density areas. This indicates that access is likely a critical component of where land deals take place for agricultural purposes, potentially due to the common implementation of agroexport models on these land grab sites.

However, there has been some indication in the literature that access may be a consequence of land grab deals, rather than a prerequisite. This is because areas with poor infrastructure, such as very rural and more forested areas that lack road development, can still be targeted by land deals of all varieties. After these deals successfully take place and an agroexport model or something similar has been established, restructuring of the local community (both physically and socioculturally) is common, and new roadways may be built for export purposes (Byerlee et al.

2016). Given that the data on access used was from 2015, and some of the land deals studied concluded before that date, this study did not discern what came first in every case, the access components or the land deal. Nevertheless, my findings suggest that investors do consider access an important factor in the spatial component of land deals, and what comes first probably varies depending on the type and location of the land deal, the capital an investor has, and many other factors.

Local laws and political economy

While a majority of tested countries for a majority of tested variables were significant, there are a variety of potential reasons for why some countries showed significance for many variables and others did not. From the data, it appears that many countries along the East African coast showed consistent significance across the variables of mean annual precipitation, aridity, and access. Interestingly enough, there are also less indigenous and community held lands in the Eastern part of Africa and more of those lands are recognized by the government relative to other regions tested (LandMark Map 2018). Additionally, only one African country has signed the 'Indigenous and Tribal Peoples Convention, 1989' which aims to recognize and protect indigenous land rights, and this country is the Central African Republic (Swepston 2015). My results for this country also indicate some sort of significance for the variables of mean annual precipitation, aridity, and access. Given that the high presence of indigenous and community held lands (especially those that are not legally recognized) and the lack of legal protections in East Africa have typically made these areas more susceptible to land grabbing, there is the potential that climate and access become less of a factor in this context (Moreda 2016). However, it is more likely that there are other complex and dynamic factors at play influencing these spatial patterns because of the lack of consistency.

Other local legal, political, and economic factors, which do not exist separate from more global dynamics, could also be helpful to explore to better contextualize my results. For example, and keeping in mind the often problematic nature and colonial history of 'development', comparing my results relative to the United Nations Human Development Index could provide some insight. Only one of my tested countries, Gabon, falls into the category of "High Human Development", and this country showed a consistent lack of significance for almost every factor.

However, this is also true for countries such as South Sudan, Rwanda, and Guinea, which fall into the opposing category of "Low Human Development" (Human Development Indices and Indicators 2018). This inconsistency could suggest that there are more complex factors at play in determining where certain bioclimatic and access factors would be significant in any one country, or could again be a result of statistical and sampling bias.

There is also benefit to exploring my results relative to each country's level of political stability as ranked by the World Bank. Tested countries that ranked above 0, meaning there exists some degree of political stability, are Ghana, Benin, Rwanda, and Sierra Leone. Most of these countries showed varying degrees of significance depending on the factor and statistical test used, except for Rwanda which showed no significance across any of the factors (Political Stability and Absence of Violence 2018). This variance is consistent with other tested countries, and there seems to be no clear trend between levels of political stability and where certain bioclimatic factors were significant or not. Again, this could be due to a variety of complex reasons, ranging from confounding sociopolitical or climatic factors to study design.

While these three measures of local legal, political, and economic aspects of the tested countries are simply entry points into the larger, more nuanced workings of inter- and intra-country dynamics, they can still be meaningful to consider with my results. On a superficial level, there does not seem to be a clear pattern between these factors and where certain bioclimatic factors may be significant or not to investors. For example, this could simply be because of sampling and statistical bias due to the number of observed land deals reported in The Land Matrix Database. It could also have something to do with other laws and policies present locally within countries from that region, both historically and contemporarily. Most likely, this inconsistency could be attributed to the nature of bioclimatic variables themselves.

It is difficult to conclude the true reason for these spatial patterns as there are highly complex and dynamic systems influencing them. As this is one of the initial studies taking a quantitative approach to exploring investor preferences of bioclimatic and access factors for agricultural land grabbing, it could be that these factors and their levels of significance are more second or third order variables. This could mean that they may not directly correlate in the same ways as the mere presence of land deals correlates to various legal, political, sociocultural, and economic factors, but rather, correlate to other factors more relevant to agriculture, something more complex, or nothing at all. However, it does seem that investors are choosing to locate land deals based on particular bioclimatic variables in these areas based on the statistical evidence, which warrants further study of these variables and their influence on investor preferences.

Global laws and political economy

Internationally, there have been few laws and policies put in place to limit these land deals and the harm they cause local communities and the environment. In regard to recognizing and protecting local communities' land rights as a means of preventing land grabbing, the international agreement on 'Voluntary guidelines on the responsible governance of tenure of land, fisheries and forests in the context of national food security' has been put in place. However, this agreement is voluntary and not all Sub-Saharan African countries have signed on. It is also typical that these land grabs occur illegally and the rights of these communities are undercut by the sheer political and economic power of the entities attempting to invest in the land (Global Witness Briefing 2016).

Additionally, any form of redress or compensation for these communities consists of navigating multiple levels of bureaucracy and red tape involving voluntary international agreements and national courts, and are undertaken by non-governmental organizations supporting these local communities and grassroots justice movements. Due to the already disenfranchised position of these communities, there is often a lack of resources necessary to adequately address the harms caused (given that such a thing is even possible considering the levels of violence). This means that often times, land grabbing entities do not face persecution, and when communities do win legal battles, the amount of compensation is often not significant enough to deter entities from investing in the country again (German et al. 2013, Macinnes 2015).

Another global intervention has been through voluntary initiatives by non-governmental organizations, the private sector, and occasionally governments, in which these organizations create self-regulating guidelines to follow that are supposed to limit land grabbing and the harms caused by them. Examples of these include the 'Land Policy Initiative (LPI) Framework and Guidelines on Land Policy in Africa' and the 'Roundtable on Sustainable Palm Oil (RSPO)' (Mwangi 2016, Ruysschaert and Salles 2014). However, there are still critical gaps in many voluntary policies that do not address land right recognition, lack oversight and meaningful reporting, and fail to adequately engage with impacted communities. Additionally, because they are voluntary, they fail to involve the multitudes of corporations whose ethical standards are not in line with the values of these agreements who are causing the most harm (Global Witness Briefing 2016).

Interestingly, there has also been intervention by some of the very organizations that are responsible for perpetuating encouraging land grabbing discourse, such as the World Bank and the Food and Agriculture Organization (FAO) of the United Nations. For example, in 2011, the World Bank released a report titled 'Rising Global Interest in Farmland: Can it Yield Sustainable and Equitable Benefits?', in which it condemned the loss land and water rights by local communities due to agricultural land grabbing. Incorporating this discourse into the broader global conversation around land grabbing is important to raise awareness and push protective policies forward. However, this same report continued to encourage foreign large scale agricultural land investments, arguing that they could be conducted in a way that is beneficial to all involved parties and even help with local 'development'. Additionally, research from this report alludes to the projected fluctuations in the price of agricultural commodities as climate change conditions make it more difficult to grow crops in many places. The same neo-colonial discourse that has been used by these organizations was implemented, such as how much "cheap" and "available" land in Sub-Saharan Africa has "large untapped potential" for "profitable" agricultural production (Deininger and Byerlee 2011).

It is clear that there exists no comprehensive international protection against land grabbing. Many of the current efforts focus more on increasing the transparency of land deals, better protecting local communities, and enhancing regulation and investor accountability (Global Witness Briefing 2016). While these are important efforts, within these initiatives is still a lack of explicit barring of land grabs themselves, which is in alignment with the policies (or lack thereof) both on a local and global level. This in part can be attributed to current neoliberal economics and related policies, under which attempts at banning or highly regulating land grabs are often futile due to the levels of systemic and institutional support and positionality many of these large investors have (McMichael 2012). All of these local and global legal, political, and economic aspects are further confirmed through my research, as my results indicate that agricultural land grabbing investments are, for a majority of tested countries and variables, still being driven in part by bioclimatic and access factors. This indicates that these interventions are still not enough to adequately address this phenomenon on a regional level.

Aridity and access correlations

The results of my exploration of the correlation between values of aridity and access where land deals were present showed that a majority of countries do not experience a correlation, which can be attributed to a variety of factors. For example, there are various sociopolitical and economic factors influencing any one country's level of infrastructure development, which may or may not rely on bioclimatic aspects. There are many arid places globally, such as many parts of Southwest Asia, that have high levels of infrastructure and access due to the presence of economically prized natural resources, like oil (Henry and Springborg 2010). Additionally, the diverse colonial history of the Sub-Saharan African region could also be a factor that influences the presence of access points more so than aridity. However, it would be incorrect to say that these more sociopolitical factors are not influenced by climate, so again there could be more of a second or third order relationship between access and aridity that is not being captured in the results of my analysis.

Limitations

There were many limitations to this research, as it is one of the first studies to explore the bioclimatic and access aspects of land grabbing quantitatively. First, there is generally a lack of information about land deals, and information that is available is highly variable in its accuracy. The data used in this study came from an open-source database where anyone with information on land deals can report them to the best of their ability, which intrinsically makes this dataset flawed and biased. Additionally, the exact location of these land deals is typically unknown due to the high degree of secrecy surrounding them, so the geocoded location reported with each land deal was used in my study without details about its level of accuracy. Third, due to the limited number of deals reported overall and within any one country, there were some countries in which only a handful of deals were present. These countries were still explored to increase the robustness of the study, but at the expense of the statistical viability of countries with a small number of land deals reported. It is difficult to conclude from a statistical standpoint what the exact number of land deals should be to ensure higher levels of statistical viability during testing, so 10 land deals were used as a baseline for a rigorous enough sample size. Finally, spatial and temporal limitations consistent with typical geospatial methods were present, such as the fineness of scale and differences in the temporality of the various tested bioclimatic and access layers.

Future directions and broader implications

This study, as one of the first studies to explore this topic using quantitative geospatial analysis, attempts to develop a new framework of methods for researching investor preferences within the realm of agricultural land grabbing, or even large scale land acquisitions more generally. There are many potential relevant data layers this geospatial overlay method can be used on, such as other biophysical factors like agricultural potential, soil composition, and distance to water sources. There is also the potential to apply these methods to sociocultural, political, and economic georeferenced data layers, such as levels of wealth or indigenous held lands within or between countries. For many non-climatic factors, application of these methods would require much more accurate geospatial data on land deals, which also needs to be improved through increased transparency in reporting by investors and vetting of open source data.

The conclusions of this study can be extrapolated to apply more broadly to other Global South countries experiencing land grabbing. Places such as Southeast Asia, Latin America, and South Asia are also experiencing high rates of agriculturally driven land grabbing as well as land grabbing for other purposes. It is likely that if climate, being that it is a relatively independent factor, is influencing investor preferences in Sub-Saharan Africa, it might play a role in these regions too. Additionally, anywhere agroexport is present, it is likely that access infrastructure needs to be closely available, so the relationship between access and investor preferences in land deals would likely apply to these places as well. More quantitative geospatial studies conducted on a global scale can help confirm these theories.

The overall results of this study, especially given the larger globalized context it is situated in, reaffirm the call for stronger protections against neocolonial land grabbing and the violence it brings. As climate change increases in its severity, including projected detrimental effects on agricultural production, understanding the bioclimatic aspects of investor preferences for these land deals will only become more critical and relevant. These initial results suggest that mean annual precipitation, aridity, and access to some degree are important variables for investors in making decisions about where to buy land within a country, which means these factors should be taken into account more explicitly within related current and future policy development and implementation. In an effort to better understand the complex dynamics involved in the land grabbing phenomenon to increase protections for local communities and the environment, more studies on the intersections of biophysical aspects and sociopolitical and economic factors must be considered.

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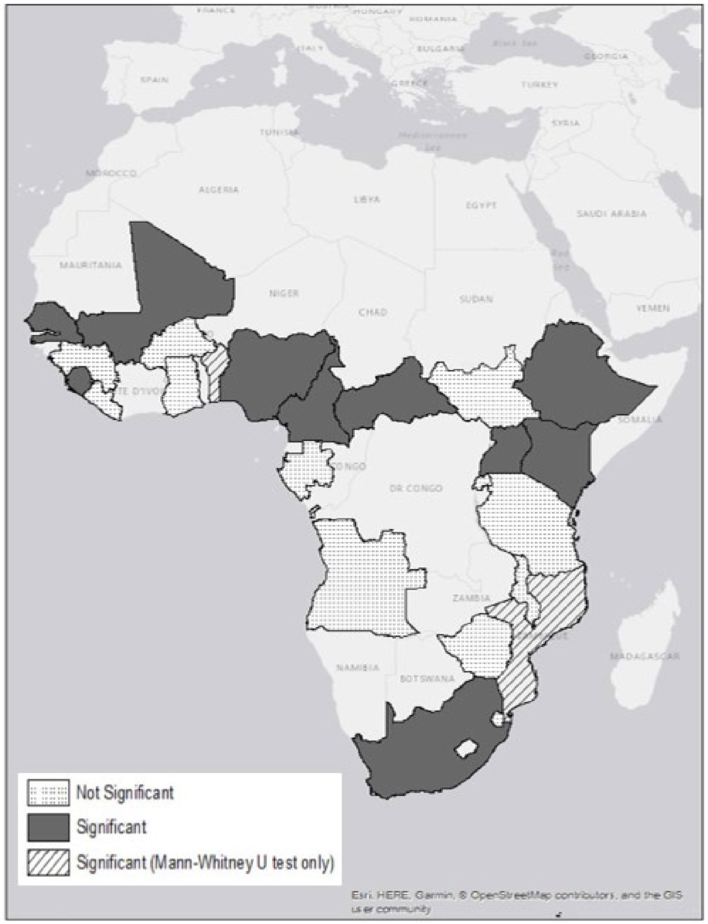
APPENDIX A: Number of land deals reported per country

Table A1. Number of land deals reported per country. This information is from The Land Matrix Database and is reflective of the number of reported deals in each tested country.

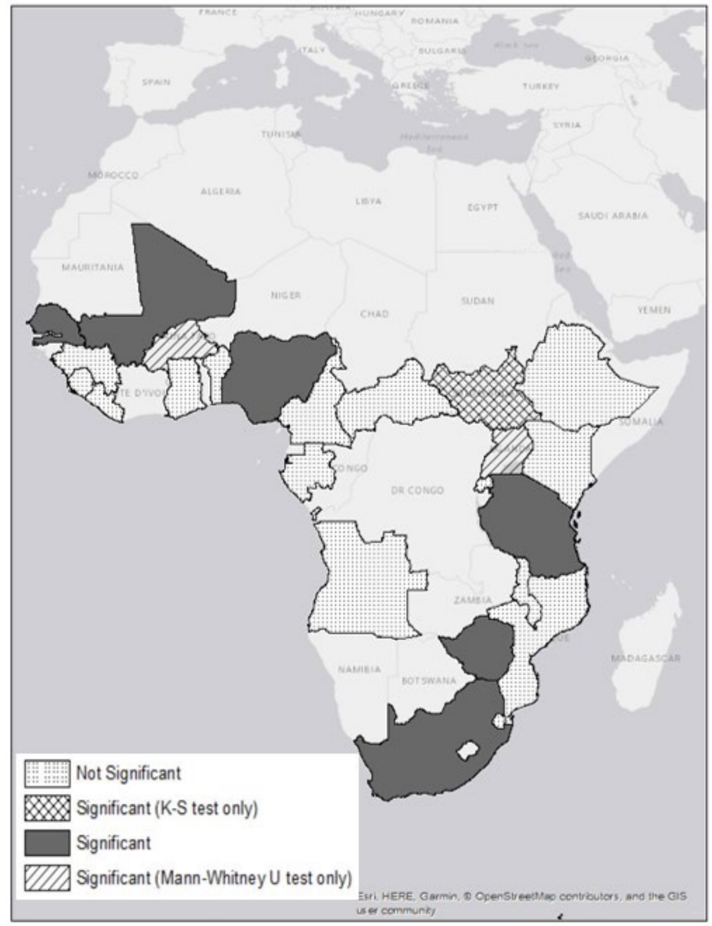
Country	Number of Land Deals Reported
Ethiopia	116
Burkina Faso*	4
South Africa	19
Mozambique	129
Zimbabwe	14
Central African Republic*	7
Kenya	41
Liberia	31
Malawi	17
Mali	25
Uganda	31
Angola	31
Benin*	7
Cameroon	21
Ghana	79
Nigeria	67
Senegal	32
Sierra Leone	32
Swaziland*	8
Tanzania	64
Gabon*	9
Guinea*	6
Rwanda	10
South Sudan	14

APPENDIX B: Results of statistical tests in each country using the 100 null point generation in comparison to land deal sites

Mean Annual Precipitation



Interannual Variability of Precipitation



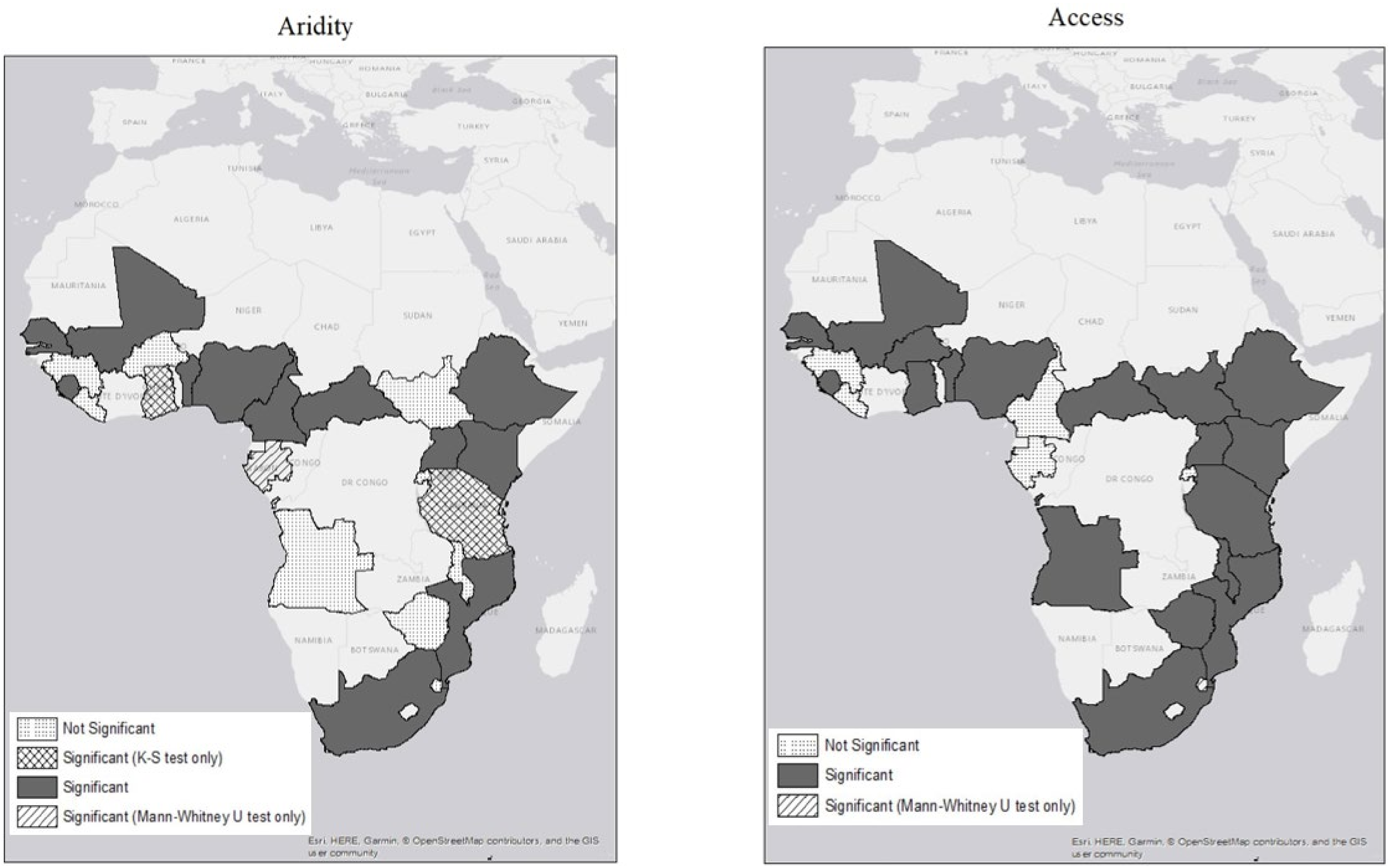


Figure B1. Results of statistical tests in each country using the 100 null point generation in comparison to land deal sites. I conducted both Mann-Whitney U tests and K-S tests for each variable for each country.

APPENDIX C: Results of the comparison of mean values of land deal point and 1000 null point distributions

Table C1. Results of the comparison of mean values of land deal point and 1000 null point distributions. I compared the mean values of histograms for each country for each climate and access variable to compare the direction of the distributions of land deal and null points.

Country	Mean Annual Precipitation of land deal points greater than null points	Interannual Variability of Precipitation of land deal points less than null points	Aridity of land deal points greater than null points	Access for land deal points less than null points
Ethiopia	Yes	Yes	Yes	Yes
Burkina Faso*	Yes	Yes	Yes	Yes
South Africa	Yes	Yes	Yes	Yes
Mozambique	Yes	Yes	Yes	Yes
Zimbabwe	Yes	No	Yes	Yes
Central African Republic*	Yes	Yes	Yes	Yes
Kenya	Yes	Yes	Yes	Yes
Liberia	Yes	No	Yes	No
Malawi	Yes	Yes	Yes	Yes
Mali	Yes	Yes	Yes	Yes

Uganda	Yes	Yes	Yes	Yes
Angola	No	No	Yes	Yes
Benin*	Yes	No	Yes	Yes
Cameroon	Yes	Yes	Yes	No
Ghana	Yes	No	Yes	Yes
Nigeria	Yes	Yes	Yes	Yes
Senegal	No	No	No	Yes
Sierra Leone	Yes	Yes	Yes	Yes
Swaziland*	Yes	No	Yes	Yes
Tanzania	Yes	No	Yes	Yes
Gabon*	Yes	Yes	Yes	Yes
Guinea*	Yes	Yes	Yes	Yes
Rwanda	Yes	No	Yes	Yes
South Sudan	Yes	No	Yes	Yes

APPENDIX D: Results of the Spearman rank correlation tests of land deal points for each country between the variables of access and aridity

Table D1. Results of the Spearman rank correlation tests of land deal points for each country between the variables of access and aridity. I used a Spearman rank correlation test to see if the variables of access and aridity were correlated based on the presence of land deal sites.

Country	Results (Significant/ Not significant, Positive/Negative/ None)	S statistic	Rho (ρ) value	p-value
Ethiopia	Not significant, None	277330	-0.06610405	0.4808
Burkina Faso*	Not significant, Negative	17.778	-0.7777778	0.2222
South Africa	Not significant, Negative	1461.1	-0.2816799	0.2427
Mozambique	Not significant, None	356570	0.003320412	0.9702
Zimbabwe	Not significant, Positive	370.35	0.1860475	0.5242
Central African Republic*	Not significant, None	56	0	1
Kenya	Not significant, Negative	14919	-0.2995751	0.05706
Liberia	Significant, Negative	7400.8	-0.4920867	0.004926
Malawi	Significant, Positive	213.88	0.7378905	0.0007212
Mali	Significant, Negative	3896.2	-0.4985334	0.0112

Uganda	Not significant, Negative	6211.2	-0.2522543	0.171
Angola	Not significant, None	5097.7	-0.02777172	0.8821
Benin*	Not significant, Negative	63.193	-0.1284458	0.7837
Cameroon	Significant, Negative	2196.3	-0.4261557	0.05406
Ghana	Not significant, Positive	73663	0.1034224	0.3644
Nigeria	Not significant, None	54388	-0.08524335	0.4928
Senegal	Not significant, Negative	6653.9	-0.2195602	0.2273
Sierra Leone	Not significant, None	5580.6	-0.02284456	0.9012
Swaziland*	Significant, Negative	159.73	-0.9015094	0.002216
Tanzania	Significant, Positive	21924	0.4980767	2.814e-05
Gabon*	Not significant, Positive	56.471	0.5294118	0.1427
Guinea*	Not significant, Negative	49.412	-0.4117647	0.4173
Rwanda	Not significant, Positive	144.36	0.1250611	0.7307
South Sudan	Not significant, Negative	681.75	-0.4983429	0.06973