INTERNAL MIGRATION AS A RESPONSE TO SOIL DEGRADATION: EVIDENCE FROM MALAWI

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Internal Migration as a Response to Soil Degradation: Evidence from Malawi *

Keiti Kondi[†] and Stefanija Veljanoska[‡]

Abstract

We study how the slow deterioration of soil, caused by climate change, affects internal migration and household resettlement. Rural households are expected to move when they face worsening soil conditions, as soil degradation is detrimental to agricultural productivity. The other possibility is that they can get stuck in a poverty trap. We use the Integrated Household Survey in Malawi for the years 2010-2016. Soil depletion is not a random process and to account for its endogeneity, we instrument soil degradation by using distant climate shocks and controlling for recent weather conditions. We find that severe soil nutrient constraints push households to send their members away. The underlying mechanism is that soil degradation is harmful to agricultural productivity, and therefore food security, which incentivizes households to seek better opportunities by pushing their members to migrate.

Keywords: land degradation, migration, internal migration, resettlement, land quality, climate change, soil nutrition

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1 Introduction

"*Men argue. Nature acts.*"
- Voltaire

According to the UNHCR, climate refugees account for more than half of all migrants.[1] A category of these migrants are the environmentally motivated one.[2] These are people who leave a constantly deteriorating environment to pre-empt the worst effects due to environmental stressors. Myers (1997) describes environmental refugees as 'individuals who no longer gain a secure livelihood in their traditional homelands because of what are primarily environmental factors of unusual scope'. There are at least 20 million environmental refugees worldwide, more than those displaced by war and political repression combined. Land degradation is one of the aspects of environmental degradation. Between 2010 and 2015, 20 percent of the worldwide land was degraded with Sub-Saharan Africa experiencing land degradation above the Globe's average.[3] In 2000, 1.33 billion people worldwide were located on degrading agricultural lands, of which 1.26 billion were in developing countries and this impacts significantly future poverty in developing countries (Barbier and Hochard, 2016).

The profound relationship between migration and the environment is not a new phenomenon, but the acceleration of climate change introduces more complexity to this relationship. Gradual environmental change, slow-onset, and sudden-onset natural disasters influence population migration decisions and patterns. Even though sudden-onset natural disasters are more likely to induce mass displacement, still a large share of people is estimated to migrate because of gradual degradation of the environment and a depletion of resources. Slow-onset disasters and gradual environmental deterioration such as reduction of soil fertility, desertification, coastal erosion, and sea-level rise, which may be associated with climate change, can have serious implications for existing livelihood patterns and production systems and may in turn induce different types of migration.

The complexity of this environment-migration nexus is subject to a fast-growing research (Millock (2015) does a summary of the literature review of this nexus). This literature focuses mainly on the

1. UNHCR's Refugee Population Statistics Database

2. According to "Internal Displacement Monitoring Center", weather-related disasters already force an average of 21.8 million people to flee their homes every year, without including displacements associated with slow-onset disasters such as drought and environmental degradation. Storms caused 12.9 million displacements worldwide 55 per cent of all weather-related disasters - by triggering mass displacement of populations living in vulnerable areas.

3. UNSTATS

climate change impact on migration decisions and finds mixed evidence (for an exhaustive review, see Section 2). The study of the incidence of slow degradation of land on migration received little attention from researchers from different fields (an exception are (Gray, 2009, Call and Gray, 2020), see Section 2). The scarcity of research on this relationship is probably related to the i) lack of granular data on the soil quality and ii) that its degradation is not a random process iii) since land degradation can happen as a slow process, the available datasets provide a downsized sample of migrants. This means that what is available in the dataset, is a sample of people that are left behind after a considerable number of people have already migrated.

In this paper, we study whether soil degradation, exacerbated through climate change, acts as a driver of internal migration. We use three waves of the Malawi Integrated Household Panel Survey (IHPS) to which data on soil quality from Harmonized World Soil Database (HWSD) is matched. We use an Instrumental variable approach (IV) to deal with the endogeneity of land degradation. Our IV consists in considering the average number of climatic shocks 15 years ago as an instrument of current land degradation while controlling for actual climate conditions. Our results, whether considering the endogeneity of soil quality or not, show that poor soil quality (soil with limited nutrient availability) initiates people to migrate. In particular, households with lands in states of severe constraints regarding soil nutrients have more family members that move between the two survey interviews.

To unpack the underlying mechanism, we further explore whether the channel through which land degradation influences migration decisions is agricultural productivity. We find that a lack of soil nutrients decreases agricultural yield, which could in turn encourage farmers to migrate. These findings are in line with a number of studies on the climate-driven migration that highlight climate change consequences on agricultural yields. We run a series of robustness checks: i) we change the type of indicator we use for soil quality; ii) we use population pressure as a proxy for degradation of soils; and iii) we run a sensitivity analysis in terms of the time window and shock thresholds in the construction of the IV. Our results are consistent across the different specifications.

The remainder of the paper is organized as follows. Section 2 reviews the related literature and describes the background of Malawi. Section 3 explains data sources, variable construction and provides summary statistics. Our econometric framework and estimation results are presented respectively in Section 4 and 5. We conclude our findings in the final section.

2 Literature Review and Background

In this section, we review the literature that studies the relationship between environment and migration. The framework of this literature is represented in Figure 1. The change of climate can affect land degradation in a fast or a slow process. Events such as hurricanes, floods, and droughts are considered fast shocks while other events can take a slower onset, like soil erosion, sea level rises, or land degradation. It is important to distinguish between the two because their effect on migration goes through different channels. Slow onset affects migration through productivity, which is different from the fast one where people resettle immediately after the shock.

Our study focuses on a slow onset process, which affects productivity and the decision to migrate internally. This fills a gap in the existing literature that considers mainly fast shocks and international migration, due to the difficulty in measuring the slow onset of land degradation. We develop the existing literature in the following sections here below.

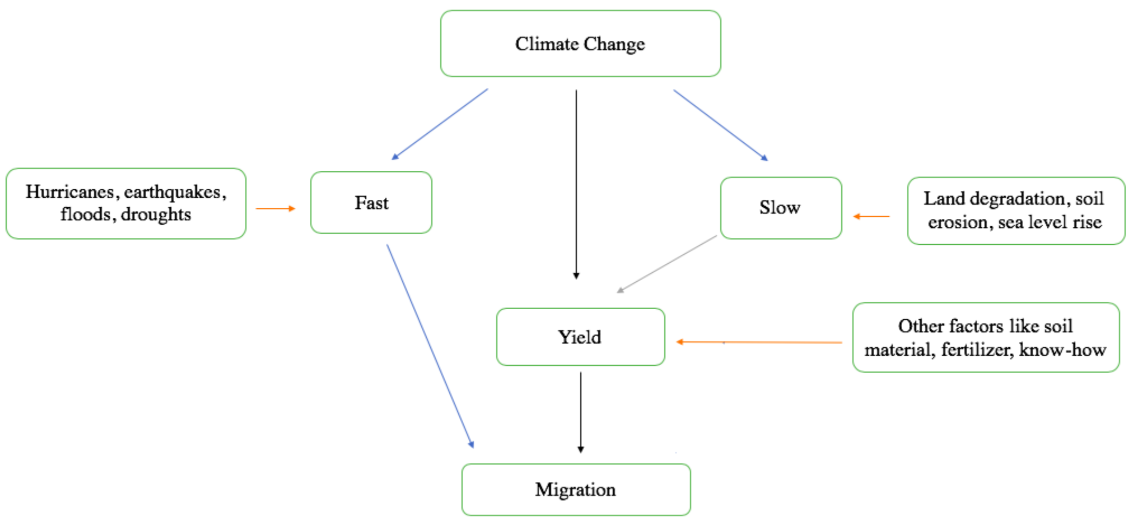

Fig. 1 – Framework of the link between climate change, land degradation and migration

2.1 Literature Review

2.1.1 Climate change and migration

Economists, ecologists, and human-environment researchers have drawn attention to the rapid rate of environmental change in many rural areas, including soil degradation, deforestation, climate change and the related displacement of potentially large numbers of environmental refugees. While most existing evidence in the literature focuses on international migration, internal migration remains understudied. Marchiori and Schumacher (2011) find that climate change will increase migration and that small impacts of climate change have a significant impact on the number of migrants. Dallmann and Millock (2017) study the impact of climate variability on internal migration by considering meteorological indicators of climate variability. They show that drought frequency in the origin state increases inter-state migration. This effect is stronger in agricultural states, and in such states, the magnitude of drought also increases inter-state migration significantly. Drought frequency in the origin state acts as a push factor on inter-state migration and it has the strongest effect on rural-rural inter-state migration. Gray (2009) finds that mean annual rainfall did not affect local migration but had a negative impact on internal and international migration. Harvest fluctuations, in contrast, increased local and regional migration, but not international migration. He concludes that international migration is the least influenced by environmental conditions, which confirms the literature's ex ante hypothesis that migration costs increase with the distance migrated. Sub-Saharan African agriculture is especially dependent on rainfall compared to most other developing countries, which triggers the potential impact of rainfall variations on economic activity. These impacts are intensified in rural areas where agriculture concentrates, and thus potentially affect rural-urban migration patterns. Drought-related changes in migration patterns, for instance, are more likely to emerge in areas where land degradation is severe (Hermans-Neumann and Hilderink, 2015). Human migration has been identified as a potentially important response to climate change. If habitation is difficult in some areas, people respond by moving into other areas. Gray and Mueller (2012a) investigate the effects of drought in rural Ethiopian highlands on population mobility over a 10-year period. They find that floods had no significant impact on migration but that weather-related crop failures increased migration. The results indicate that men's labor migration increases with drought and that land-poor households are the most vulnerable. However, marriage-related moves by women also decrease with drought. Coniglio and Pesce (2015) find that a large fall in average temperature during the rainy season increases out-migration, in particular in less developed economies. The magnitude of these effects is substantially smaller if these shocks occur during the dry season. [4] Policies regarding extreme weather events are especially valuable in resource-poor settings where climate-related vulnerability is high, such as for smallholder farmers in the developing world. Brausmann *et al.* (2019) show that there can be potentially large welfare gains from incorporating improved meteorological services into their decision-making process.

4. Also Bohra-Mishra *et al.* (2014) find that in 7000 households in Indonesia, an increase in temperature (e.g., due to natural variations or global warming) and, to a lesser extent, variations in rainfall are likely to have a greater effect on permanent out-migration of households than natural disasters. They find that rainfall has a quadratic effect such that in conditions that are initially dry, a decline in rainfall tends to increase migration, whereas, in wetter conditions, an increase in rainfall increases migration.

2.1.2 Environmental determinants of migration

Environmental factors that act over the long term, [5] such as soil erosion and decline of water availability and quality can affect migration decisions. LeBlanc and Perez (2008) find a positive correlation between rainfall and population density in the African continent below an annual rainfall of 900 mm. Density increases across the continent should lead to a significant increase in the extent of water-stressed zones. Changes in rainfall, the pattern of which remains inherently uncertain today mitigate those effects. Wisner *et al.* (2004) writes that not only nature but also economic, social, and political factors are also affected by the consequences of natural hazards. There are a fast-growing number of people who can no longer gain a secure livelihood in their homelands because of drought, soil erosion, desertification, deforestation, and other environmental problems like in (Myers, 1997). Adverse environmental conditions have a tendency to increase migration but this is not always the case. Gray (2011) finds that soil quality significantly reduces migration in Kenya, particularly for temporary labor migration, but marginally increases migration in Uganda.

2.1.3 Climate change and productivity

Environmental changes affect agriculture through production and income effects. Climate change has changed urbanization in sub-Saharan Africa and it has been an important determinant of rural-urban migration. Weather, proxied by rainfall and temperature can be considered an input in the production function. It can also affect income by adjusting wages and general equilibrium effects like in (Barrios *et al.*, 2006, Marchiori *et al.*, 2012). Brausmann *et al.* (2019) study the high climate vulnerabilities of smallholders in the Peruvian Altiplano and they show that access to existing meteorological services is empirically associated with avoided losses in agricultural production that amount to 18 dollars on average per household and per year.

A mechanism by which the environmental variables influence migration is temperature, which is known to have a dominant influence on economic conditions (Schlenker and Roberts, 2009, Schlenker and Lobell, 2010). Dell *et al.* (2009) show that for the year 2000 countries are, on average, 8.5 percent poorer per capita per 1 degree Celsius warmer. [6] Hsiang (2010) finds that national output falls by 2.5 % for a 1 degree Celcius increase in temperature in Caribbean countries during

5. To be distinguished from sudden shocks like natural disasters (Gray and Mueller, 2012c) and Beine and Parsons (2015) find higher internal migration after natural disasters and other find ambiguous or even negative effects like Gray and Mueller (2012b) and Tse (2011). Tse (2011) finds that earthquakes reduce the household size, earnings, and non-business assets, each of which tends to reduce migration rates. Volcanic eruptions on the other hand raise the value of farmland, which, in turn, reduces migration

6. In another world sample from 1950 to 2003, they find that being 1 degree C (Celsius) warmer in a given year reduces per capita income by 1.4 %, but only in poor countries. Moreover, they estimate the model with lags in temperature and they find that this large effect is not reversed once the temperature shock is over, meaning that temperature is affecting not only income levels but also growth levels, which have economic consequences in the longer run.

1970-2006. Schlenker and Roberts (2009) find that for US, yields increase with temperature up to 29 degrees C for corn, 30 degrees C for soybeans, and 32 degrees C for cotton but that temperatures above these thresholds are very harmful. Malpede and Percoco (2021) find that areas that experienced large soil aridification reduced the GDPs of African and Asian countries by 12 % and 2.7 %, respectively.

2.1.4 Productivity, wealth and migration

There is evidence that sudden-onset environmental events affect migration. Dust storms have affected the movement of people by causing a decrease in output in agriculture and the value of land (Gutmann *et al.*, 2005). Gröger and Zylberberg (2016) find that internal labor migration facilitates shock coping in rural economies. Following a massive drop in income, due to a disastrous typhoon shock, households cope mainly through labor migration to urban areas. Non-migrant households react by sending new members away who then remit, and households with settled migrants ex-ante receive more remittances. Schlenker and Lobell (2010) studies the negative impact of climate change on African agriculture. [7] Hornbeck (2012) finds that adaptation through changes in crop choice was relatively minor and that adaptation occurred mainly through migration.

Many regions, especially developing countries, are expected to experience significant declines in agricultural yields as a result of projected warming. Feng *et al.* (2010) study the relationship between crop yields and migration. They find that a 10 percent reduction in crop yields in Mexico would lead an additional 2 percent of the population to emigrate to the United States. Dell *et al.* (2012) find that higher temperatures have substantial negative impacts in poor countries. They substantially reduce economic growth in poor countries, as well as agricultural output, industrial output, and political stability. [8]

2.2 Background

We focus our study on Malawi, a country in Sub-Saharan Africa, which relies highly on agriculture and that has been affected strongly by land degradation. Malawi is both one of the least urbanized

7. Crops affected are maize, sorghum, millet, groundnut, and cassava. They also find that countries with the highest average yields have the largest projected yield losses, suggesting that well-fertilized modern seed varieties are more susceptible to heat-related losses.

8. Lack of resources can also affect conflicts which lead to migration. Environmental distress, changes in landscape, and soil material associated with scarcity of resources can also cause conflicts. Poor societies will be particularly affected since they are less able to buffer themselves from environmental scarcities and the social crises they cause. These societies are, in fact, already suffering acute hardship from shortages of water, forests, and especially fertile land (Homer-Dixon, 1991, 1994)

countries in the world and has one of the highest rates of urban population growth.[9] [10]

2.2.1 Agriculture and Climate in Malawi

According to the World Bank, the agricultural sector contributed to the Malawian GDP by 30 percent in 2017. It generates over 80 percent of national export earnings and it concerns 64.1 percent of the labor workforce comprising mostly the smallholders subsistence farmers. Approximately 83 percent of the Malawian population leaves in rural areas and agriculture remains the primary economic activity. The majority of the population engages in smallholders, rain-fed agriculture production and only about 4 percent of the cultivatable land is under irrigation. The growing season is between November and May, whereas the rest of the year is characterized by a dry season. During the dry season, only a small number of farmers can exploit the residual moisture in valley floors (dambos).[11] Malawi has experienced extreme weather episodes in the last years, both droughts and floods, which made the country highly vulnerable to climate variability, which is only expected to worsen under a warmer climate future. It is one of Southern Africa's most densely populated countries, with a population of about 17 million people spread over an area of 118,484 square kilometers. Its land is under extreme pressure with 200 people per square kilometer. Malawi is a landlocked, low-income, and agricultural-based economy (World-Bank, 2017). According to the Agriculture Public Expenditure Review report (2013), Malawi is getting around 21 percent of the national budget expenditure exceeding the Maputo declaration which recommended a 10 percent support to agriculture. Despite this, the land for agriculture in Malawi is becoming limited and affected by erosion linked to the increasing deforestation.

2.2.2 Migration in Malawi

Our hypothesis is that households opt for other off-farm opportunities if land degrades or they consider migration to avoid poverty.[12] Agricultural environments become more attractive and can pull households from seeking better opportunities elsewhere and thus migrate. Among other factors motivating migration in Malawi are economic reasons, marriage, or divorce. The country has witnessed a massive increase in internal migration, both rural-to-rural and rural-to-urban, and the bulk of migration experiences for Malawians today remain internal (Englund, 2002). Following natural disasters since the late 1970s related to drought, fires, floods, and landslides, the

9. It is estimated that in Africa, 51 percent of the poorest people occupy marginal lands; in Asia, 60 percent; and in Latin America, 80 percent (Myers, 1997).

10. International Organization for Migration IOM: Migration in Malawi, A Country Profile 2014.

11. Agriculture is also the main contributor to the national and household food security and nutrition. The main crops are maize, rice, sorghum, bananas, cassava, sweet potatoes, Irish potatoes, and legumes and the main industries deal with the agricultural processing of tobacco, tea, sugar, and timber products.

12. Addressing the Land Degradation, Migration Nexus: The Role of the United Nations Convention to Combat Desertification 2019, Gray and Mueller (2012a)

country has experienced numerous incidents of internal displacement. [13] International migration in Malawi has been decreasing from 1990 to 2013 for both sexes.[14] Rural residence is predominant: the vast majority of the Malawian population resides in rural areas, and the majority of rural migrants move to other rural areas instead of urban centers (Anglewicz *et al.*, 2017)

3 Data

We use two sources of data to analyze the interplay between the slow degradation of land and migration decisions. The household and plot data is from the Malawi Integrated Household Panel Survey (IHPS) which is a three-year survey conducted by the National Statistical Office of Malawi, with assistance from the World Bank. The panel survey develops from the Integrated Household Survey (IHS), which collects information on individuals, households, plots, and community-level characteristics of 12,288 households interviewed during the rainy season 2010/2011 - Third Integrated Household Survey (IHS3).[15] The panel component of this sample includes 1,619 that were further re-tracked and interviewed in 2013 - Fourth Integrated Household Survey (IHS4). Our sub-sample includes 1334 households in each wave where original nucleus households present in the three waves are taken into consideration. In Figure 2 can be found a timeline of the data on temperature, land quality, and migration, the main variables that we use in this study.

Our dependent variable is constructed using the IHPS information on individual migration outflows and household resettlement. The former indicates whether a family member migrated in the 6 months preceding the interview. The latter indicates whether the household has resettled at least 10 km away from the origin place in the first survey wave. We choose 10 km as threshold. [16] With this specific distance we do not consider the very short moves. Yet, taking into account that the distance to a main road is on average 7.5 km, 10 km can be considered a resettlement distance for Malawi standards.[17] According to Table 6, 6% of households have a migrant that has left in the past 6 months and 0.09 is the average number of migrants that left households in the last 6 months. 5% of households have resettled more than 10 km away since the previous wave.

13. It is estimated that between 1979 and 2008, natural disasters in Malawi affected an estimated 21.7 million people and killed 2,596 people (International Disaster Response Law (IDRL) in Malawi 2015)

14. International Organization for Migration IOM: Migration in Malawi, a country profile 2014

15. The longitudinal panel dataset IHPS consists of five core questionnaire instruments; the Household Questionnaire, the Agriculture Questionnaire, the Fishery Questionnaire, the Community Questionnaire, and the Individual Questionnaire. We use the agriculture and the household questionnaire. We use this survey data because it is the only one that provides a panel (longitudinal dimension), the use of technology: GPS for households location and plots, descriptively exploits geo-spatial variables, household characteristics, the decision to migrate, and because it is open data. Malawi data has more than 12000 respondents different from the other LSMS countries that have around 3000-4000

16. Chort *et al.* (2018) uses 5km distance while Kubik and Maurel (2016) uses 10km. Other papers use like Hirvonen (2016) 'nearby village' as distance measure

17. In the Robustness Section we account for different distance thresholds to study not only the link between land degradation and migration, but also the one between land degradation and distance of move.

We use two measures to evaluate soil quality, our variable of interest. The first measure is a subjective one, that captures the perceived land quality from the perspective of the farmer. The IPHS includes descriptive information on the farmer's perceived soil quality of each of the households operated plots.[18] The objective measure is incorporated as a part of the Geo-variables provided by the World Bank together with IPHS and originally comes from the Harmonized World Soil Database (HWSD v 1.21, used by WB) established by international institute for applied systems analysis and FAO.

We follow the development economics literature in using weather variables as instruments to identify shocks. By 'weather' we refer to temperature and precipitation at a specific time and place. By 'climate change' we refer to a permanent change in the average long-term levels of temperature and precipitation, and by 'climate variability' we refer to a permanent change in the long-term variance around the average levels (Deschênes and Greenstone, 2007). We are interested in climatic changes, rather than permanent cross-country climatic differences in levels.

To study migration in response to slow-onset changes, periods longer than a few years must be taken into account, given the long response time of these changes. We use data from the National Oceanic and Atmospheric Administration (NOAA) and from the European Centre for Medium-Range Weather Forecasts (ECMWF). According to the World Bank, the mean annual temperature in Malawi increased by 0.9 degrees Celcius during the period 1960 to 2006 (World Bank, 2012). The average increase in temperature is concentrated in the rainy summer season (December–February).

We compute a Standardized Precipitation Index SPI based on the information included in the previous dataset, which is a widely used index to characterize meteorological drought on a range of timescales. On short timescales, it uses soil moisture as a short term and groundwater and reservoir storage as a long time indicator.[19] The SPI specifically addresses the intensity of meteorological drought or precipitation deficit. The shortage of precipitation is a fundamental, intuitive metric for drought. The IHPS survey provides the GPS location (latitude and longitude) of the 197 enumerator areas addressed by the survey, so we can merge the socio-economic data with the rainfall and temperature records from two sources. Our SPI score accounts for rainfall anomalies starting from 15 years before the start of the survey until 25 years backward. For example for the survey of 2010, which is answered in 2008-2009, SPI measures are for the years 1983-1993.[20]

18. The question asked in the survey is the following: "What is the soil quality of this plot"? The proposed answer options are 1 - Good; 2 - Fair and 3 - Poor. To have an overall evaluation of the soil quality evaluated by a given farmer on all of its land holdings, we construct a weighted subjective measure where we weight each type of land quality, good, fair, and poor, by the size share of the corresponding plot in the total land holdings.

19. John Keyantash, National Center for Atmospheric Research Staff (Eds.), The Climate Data Guide: Standardized Precipitation Index (SPI) (2018)

20. For the survey in 2013, whose data was collected during 2011-2012, SPI measures are collected for the years 1986-1996. For the survey in 2016, whose data was collected during 2014-2015, SPI measures are based on the years 1989-1999.

We also account for observed intrinsic household characteristics like age, sex, education, household size, and a dummy on rural or urban areas. Degradation of environmental conditions can contribute to out-migration, while in-migration can cause environmental changes at the immigrants' destination. High population density places additional stress on local natural resources (Hermans-Neumann *et al.*, 2017). Thus, we also control for district population density. We consider these characteristics to further explore different behavior in the households and community. Our sample has a household size of 5 members on average and 2.45 of them belong to the age group 14-60. 25% of households live in urban areas. 23% of households are of a female head. The average years of education in the family is 5.56. 56% of households are credit constrained. The distance of a household from the main road is 7.75 km on average. More information on descriptive statistics can be found in the summary statistics of Appendix D.

Maps of Malawi regarding land quality, migration patterns, and climate change are shown in Appendix E. Land quality is perceived as worst in the southern part of the country. The south and the center are the most exploited areas in the country in terms of agriculture. They were also the areas in which the estate and state sector was established, which had a negative effect on the production capacity of the smallholders' sector (Green, 2007). The subjective land quality is correlated to a high Topographic Wetness Index (TWI), shown in Figure 4 of the same appendix.[21] The objective land quality shows a decrease in nutrient availability in 2 regions, respectively in the center and the south of the country. Internal migration patterns are heterogeneous but they seem to increase in the central part of the country from 2010 to 2013 and in the southern part of Malawi from 2010/2013 to 2016. Internal migration in the north decreases during these years. Resettlement gets stronger in the central area of the country and one region of the north. An explanation is a search for unused, arable land, considering both a primarily agricultural base and a high birth rate (IOM, 2014).

21. Topographic Wetness Index (TWI) expresses the terrain-driven balance of the catchment water supply and local drainage.

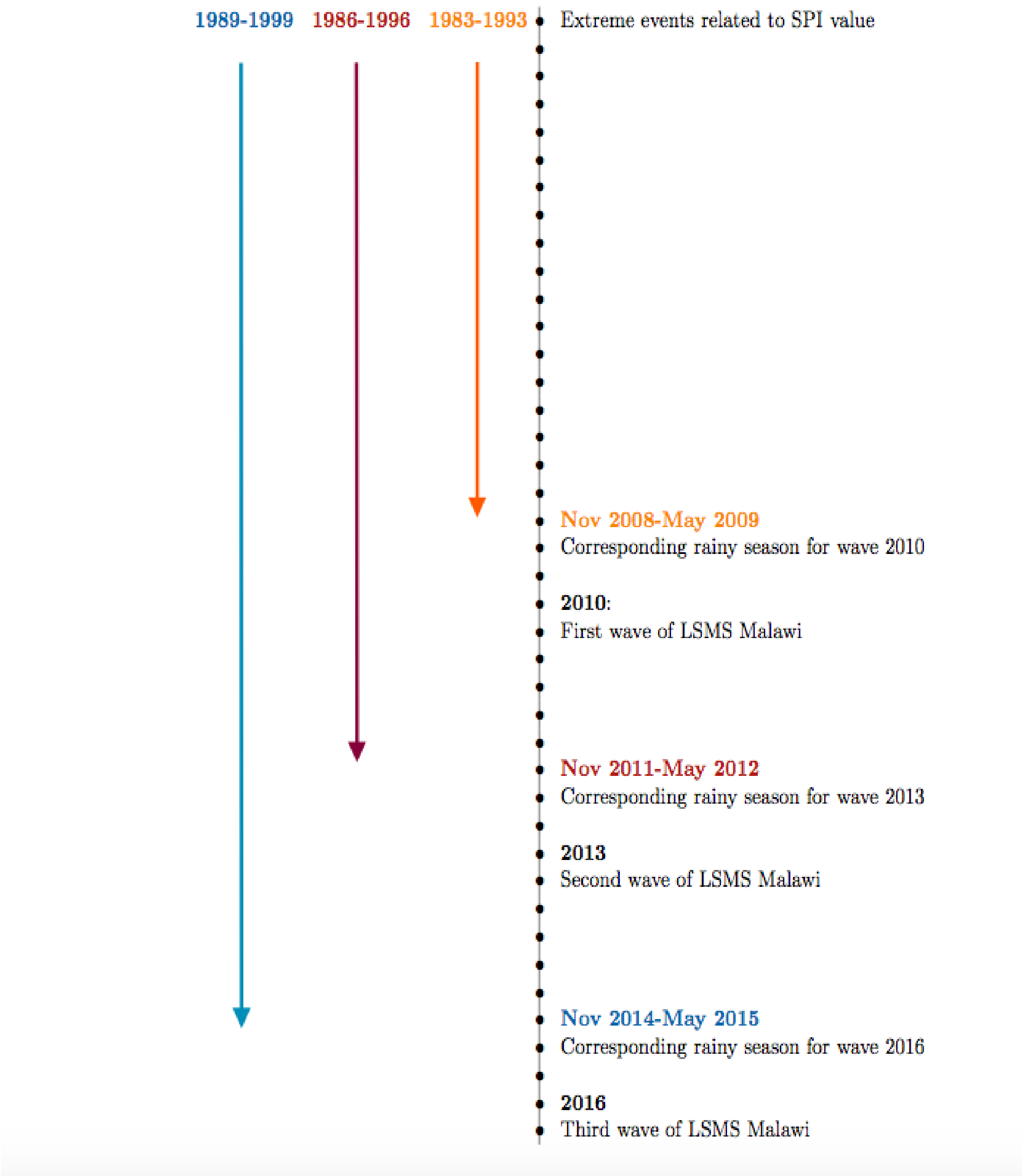

Fig. 2 – Timeline of the data on SPI, land quality and migration

4 Identification Strategy

In this section, we discuss the empirical approach that we adopt to study the impact of land degradation as a possible push migration factor. We describe the different identification issues and propose an IV framework to reduce the bias in the estimates. The main estimation equation is as follows:

$$M_{ht} = \alpha_0 + \alpha_1 LD_{ht} + X'_{ht}\alpha_2 + \alpha_3 R_{ct} + \eta_t + \varepsilon_{ht} \tag{1}$$

where M_{ht} is the migration of a given household h or member of a household h in year t. We use three different variables: a dummy variable if a member of a household (HH) migrated in the 12 months preceding the interview; a variable of the total number of HH migrants; and whether the whole HH moved more than 10 km away. We aim to consider different types of movements as migration responses to soil degradation might be heterogeneous. In particular, we would like to evaluate to which extent soil degradation affects individual migration, both on the intensive and extensive margin, as well as the collective, household migration. LD_{ht} stands for land degradation with capturing the soil nutrients availability. It is a categorical variable based on the qualitative evaluation of the Harmonized World Soil Database.[22] It takes value one if a HH faces severe nutrient availability constraints, zero otherwise. Household characteristics are represented in the vector X_{ht}, which includes the household head's gender, age, average years of education, whether the HH lives in an urban area, a dummy variable indicating if a HH is credit constrained and wealth quantiles determined by principal component analysis. R_{ct} is a dummy variable indicating if there was a rainfall anomaly based on the SPI score (SPI<-1.28) in the community c where household h belongs in year t. η_t gathers time dummies.

If Equation (1) is estimated by using Ordinary Least Squares (OLS), $\hat{\alpha_1}$ - $\hat{\alpha_3}$ will be biased. Land degradation is not a random process - it depends on different environmental factors that can influence migration, and other individual or household decisions while modifying/controlling for its degree. In this sense, endogeneity sources can be of the three traditional kinds: selection bias, omitted variables, and reverse causality. First, households that tend to improve land quality or operate with the land of better quality might be systematically different from those who have access to the land of poor quality. Such systematic differences could affect different household decisions including migration ones. Second, there might be some observable or unobservable individual and household characteristics (e.g. entrepreneurial spirit of farmers) that could simultaneously affect migration decisions and the degree of land quality of the operated land. Introducing household fixed effects in Equation (1) would purge the time-invariant household characteristics.

22. Harmonized World Soil Database 2012

However, the time-variant unobservable characteristics would remain. Land degradation being a gradual process that varies mildly over time, including household fixed effects in Equation (1) would limit the possibility to estimate any effect of land degradation on migration because of low within variability. Therefore, we estimate our main specification by using a pooled OLS model, we cluster the error term, ε_{ht}, at the household level and we tackle omitted variable bias by adopting an IV approach. Finally, reverse causality between migration and land degradation can arise and bias the estimates. In particular, households who have migrants have a lower endowment of farm labor which can have an incidence on the adoption of other farming inputs such as fertilizers. We address the different types of bias by instrumenting the degree of land degradation using climatic events that occurred far away in time while controlling for current events through R_{ct}.

The first stage estimation equation is defined as follows:

$$LD_{ht} = \beta_0 + \beta_1 R_{ct-15} + \beta_2 R_{ct} + X'_{ht}\beta_3 + \eta_t + \nu_{ht} \tag{2}$$

where LD_{ht} indicates whether a household faces severe soil nutrient availability constraints in year t. R_{ct-15} is the instrumental variable and it represents the average number of negative precipitation anomalies (SPI<-1.28) since 1983, related to the first date of the LSMS data availability, till 15 years before the year of survey in the community c where the household currently belongs.[23] The drivers of land degradation can be of environmental and human nature (Olsson *et al.*, 2019). Among the environmental drivers, the climatologist literature has identified gradual changes in precipitation, temperature, and wind, including distribution and intensity of extreme events among the main climate-change drivers of land degradation (Lin *et al.*, 2017, Olsson *et al.*, 2019). Distant past rainfall changes have long-run consequences through their direct implications for land degradation, but they are less likely to directly influence current migration decisions which are more likely to be subject to recent weather events. To account for such temporal correlation weather conditions, we control for both past rainfall changes R_{ct-15}, and current R_{ct} precipitation anomalies. In this sense, we assume that past rainfall changes affect migration decisions through their impact on land degradation.[24] Further, we account for the same household characteristics that are represented in the vector X_{ht} and time dummies included in η_t.

23. In the Robustness checks section we do the analysis modifying this threshold and the results in the first and second stage of our analysis are consistent.

24. It should be noted that past extreme weather events could have other political (e.g. conflicts) and socio-economic (e.g. prices and food security variations) events consequences which affects human movements. Therefore, it is important to acknowledge that exclusion restrictions are not fully satisfied in this framework. Yet, we show the test scores of standard IV tests to examine the relevance of the instrument we select.

5 Results

In this section, we discuss the different results of the empirical specification described in the above section. We first focus on commenting on the estimation results from the specification that does not account for the endogeneity issues (LPM hereafter). We then turn to discuss the estimates from the IV specification. In particular, we first focus on the stage regression results and comment on the relevance of the instrument, and then we discuss and compare the second stage results with respect to the LPM specification.

The results are shown in Table 1. The table is organized into 3 panels. It shows the impact of soil nutrient constraints on 3 types of migration: 1) when the household has a migrant, 2) the number of household migrants and 3) when the household resettles more than 10 km away. We find that severe constraints of soil nutrients have a statistically significant and positive effect on the probability of having a migrant and on the number of migrants within a household. Similarly, households facing severe soil constraints have more family members that move away than households that do not face such constraints. This is not the case when we examine the impact of severe soil constraints on resettlement. The absence of such an effect can be related to a 'poverty trap' argument, as household resettlement might imply higher costs of migration than individual migration. When land degrades, its productivity lowers, and cannot provide sufficient income that covers costs to resettle. In terms of magnitude, severe soil constraints increase the probability of having a migrant by 5.4 % compared to households that do not face such constraints. Regarding the intensive margin, the impact is relatively low: the number of migrants of households dealing with severe soil constraints is 0.05 higher than households with better soil conditions.

Regarding wealth, we find that richer people resettle more. Households belonging to the third wealth tercile are associated with a higher probability of household resettlement than the households with lower wealth levels. However, this impact is only significant at a ten percent level of statistical significance and is not observed for the other types of migration. Being in the third tercile of wealth increases the probability of resettlement for more than 10 km by 1.8 % compared to households belonging to the other wealth terciles. Previous studies like Dustmann and Okatenko (2014) and McKenzie and Rapoport (2007) also show that wealth is an important determinant of migration.

Education of the household head is positively associated with household having a migrant and the number of migrants per household. It is statistically significant with the household resettlement. One more year of education increases the probability of resettlement by 0.2 %. Our results are in line with the ones of Docquier *et al.* (2014), Mountford and Rapoport (2011, 2012) as more educated people not only resettle more but also have more migrants that left home. Age does not affect the first and second type of migration. Age is statistically significant at a one percent level for household resettlement. An increase in the age of the household head by one year decreases the probability of resettlement by 0.1 %. In the literature, younger people migrate more like in Chort *et al.* (2018) and Stark and Bloom (1985). Here we look at the age of the household head, where experience might be useful when making decisions to resettle the whole household. Female household heads increase the probability that the household has a migrant by 3.3 % compared to male household heads. It is in line with Chort *et al.* (2018) but also with literature that gender matters in migration (Bertoli and Marchetta, 2012). This is significant at the one percent level. It also increases the number of migrants by 0.07 at a one percent significance level. It is not statistically significant for the resettlement measure and it is associated negatively to it.

Household size is significant at the 1 percent level for both measure 1) and 2) of migration but not for measures 3). An increase by one member in household size increases the probability that the household has a migrant by 1 % and the number of migrants by 0.023. It is associated negatively with resettlement. The credit constraint of the household is associated negatively with measures 1) and 3) of migration but positively with measure 2). We can say the same about the location of the household, specifically urban areas households. The biggest driver to explain migration and the number of migrants is household size. 1 standard deviation increase in household size boosts migration by 9 % and the number of migrants by 11 %. Severe constraints is the second biggest driver explaining migration. 1 standard deviation increase in the severe constraints, boosts the number of migrants by 8 %. Age is the determinant in resettlement. 1 standard deviation increase in the age of household head, diminished the number of migrants by 7 %.

Negative deviations from the rainfall level is not significant. It is positively associated with the 3 measures of migration. We do not find such an impact because there were not too many shocks during the period.

Instrumental Variable: We consider the average number of climate events 15 years ago as an instrument of climate change and its effects on soil nutrients. Since soil quality is difficult to measure we consider a proxy. We use this instrument as it is strongly correlated with soil quality and it is independent of migration.

The first stage results are presented in Table 2. We find that the average number of extreme climate events that occurred 15 years prior to the year of the survey is a significant and strong determinant of severe constraint in terms of soil nutrients. An increase of the average number of climate events by 1, increases the probability of having a highly severe soil constraint by 59.3 %. Negative rainfall shock is not significant but it is associated positively with the severe constraints of the soil nutrients. This is the biggest driver of soil quality. 1 standard deviation increase in negative rainfall shock, boosts severe constraint by 59 %. Looking at the household characteristics, we see that the education of household head and the urban location of the household are also statistically significant. Being in an urban area affects negatively the severity of soil in terms of nutrients. Location in an urban area is the second biggest driver of soil quality. Having a high education of the household head affects negatively the severity of soil in terms of nutrients. An increase of 1 year of education for the household head of the family, lowers the constraint severity of the soil nutrients by 0.3 %. When the household is in an urban area, the constraint severity of soil nutrients lowers by 17.2 %. Household size is significant at the ten percent level. An increase of the household by 1 more member raises the constraint severity of the soil nutrients by 0.3 %. Having a female household head is associated with fewer soil nutrient constraints. Age does not affect the first and second type of migration. There is no difference between different ages of the household head. Location is statistically significant at the one percent level. Households that have land in urban areas have 17.2 % more severe constraints regarding the soil nutrients of their lands. Wealth and credit constraints are associated positively with the dependent variable but they are not statistically significant.

The second stage results are presented in Table 3. The table is organized into 3 panels. Severe constraints on soil nutrients is statistically significant in households that have a migrant that has left home. An increase in severity of 1 degree of the soil nutrients raises the probability that households have a migrant by 22.9 %. It is associated positively with the 2) and the 3) measures of migration but it is not significant. Severe constraints is the biggest driver of migration and the number of migrants. An increase of 1 standard deviation of severe constraints boosts migration by 31 % and the number of migrants by 18.8 %. When rainfall shocks are negative, it increases the probability that the household has a migrant by 2.9 %. This is significant at the five percent level. It also raises the number of migrants by 4 % and it is significant at the ten percent level. Furthermore, it is associated positively with the 3) measure of migration. Focusing on the household characteristics, the education of the household head is positively associated to the 1) and the 2) measure of migration. It is significant at one percent for the third measure of migration. An increase of 1 year of education for the household head, raises the probability of household resettlement by 0.3 %. Age does not affect the first and second type of migration. Age is significant at the one percent level for the 3) measure of migration. It is the biggest driver of resettlement, although its effect is negative. One year older heads of household resettle less by 0.1 %. Having a female as head of household is significant for the first and the second measure of migration. It is associated negatively for the third measure. Having a female household head increases the chances that the household has a migrant by 3.2 % and increases the number of migrants by 7.1 %. Household size is the biggest driver of migration out of all household characteristics. It is significant at the one percent level for the first and the second measure of migration. It is associated negatively with the third measure of migration. An increase in the household size by 1 member, increases the chances of households having a migrant by 1 % and increases the number of migrants by 2.3 %. Being in an urban area is negatively associated with migration. It is significant at the ten percent level for the first measure of migration. Being in an urban area lowers by 3.5 % the chances that the households have migrants. Credit constraint is negatively associated with migration. Being in the second tercile of wealth is positively associated with the first and the second measure of migration but negatively with the third. Being in the third tercile of wealth is positively associated to the first measure of migration, negatively to the third and it is significant at the 10 % level for the third. Households that are in the third tercile of wealth resettle by 1.7 % more. Overall our results that livelihoods are increasingly challenged by the dual threats of land degradation and climate change are consistent with Call and Gray (2020).

Table 1 – The impact of soil nutrient constraint of different forms of migration

	(1) HH has a migrant	(2) Number of HH migrants	(3) Resettlement > 10km
Severe constraint: soil nutrients	0.054***	0.050*	0.014
	(0.02)	(0.03)	(0.03)
Negative rainfall shock	0.024	0.036	0.002
	(0.02)	(0.03)	(0.01)
Education of HH head	0.002	0.002	0.003**
	(0.00)	(0.00)	(0.00)
Age of HH head	0.000	0.000	-0.001***
	(0.00)	(0.00)	(0.00)
Female HH head	0.033***	0.070***	-0.003
	(0.01)	(0.03)	(0.01)
HH size	0.010***	0.023***	-0.001
	(0.00)	(0.01)	(0.00)
HH is credit constrained	-0.013	-0.001	-0.002
	(0.01)	(0.01)	(0.01)
Urban HH	-0.004	0.006	-0.015
	(0.01)	(0.02)	(0.01)
2nd tercile wealth	0.006	0.015	-0.002
	(0.01)	(0.02)	(0.01)
3rd tercile wealth	0.006	0.001	0.018*
	(0.01)	(0.02)	(0.01)
Obs.	3,694	3,694	3,694
R^2	0.021	0.021	0.039

Note: Standard errors in parenthesis are clustered at household level. The negative rainfall anomaly is a binary variable indicating if SPI is lower than -1.28. Time dummies are included in the specification. Significant coefficients are denoted with stars as follows: *** p<0.01, ** p<0.05, and * p<0.1.

Table 2 – First Stage Results: Past Climate as IV

	Severe constraint: soil nutrients
Average number of climate events 15 years ago	0.593***
	(0.06)
Negative rainfall shock	0.008
	(0.01)
Education of HH head	0.003***
	(0.00)
Age of HH head	-0.000
	(0.00)
Female HH head	-0.008
	(0.01)
HH size	0.003*
	(0.00)
HH is credit constrained	0.007
	(0.01)
Urban HH	0.172***
	(0.01)
2nd tercile wealth	0.014
	(0.01)
3rd tercile wealth	0.010
	(0.01)
Nr. observations	3,694

Note: Standard errors in paranthesis are clustered at household level. The negative raifall annomaly is a binary variable indicating if SPI is lower than -1.28. Time dummies are inclded in the specification. Significant coefficients are denoted with stars as follows: *** $p<0.01$, ** $p<0.05$, and * $p<0.1$.

Table 3 – Second Stage: the impact of soil nutrient constraint of different forms of migration

	(1) HH has a migrant	(2) Number of HH migrants	(3) Resettlement > 10km
Severe constraint: soil nutrients	0.229**	0.188	0.031
	(0.10)	(0.18)	(0.08)
Negative rainfall shock	0.029**	0.040*	0.002
	(0.01)	(0.02)	(0.01)
Education of HH head	0.001	0.002	0.003***
	(0.00)	(0.00)	(0.00)
Age of HH head	0.000	0.000	-0.001***
	(0.00)	(0.00)	(0.00)
Female HH head	0.032***	0.071***	-0.004
	(0.01)	(0.02)	(0.01)
HH size	0.010***	0.023***	-0.001
	(0.00)	(0.00)	(0.00)
HH is credit constrained	-0.014*	-0.002	-0.002
	(0.01)	(0.01)	(0.01)
Urban HH	-0.035*	-0.018	-0.015
	(0.02)	(0.04)	(0.02)
2nd tercile wealth	0.003	0.013	-0.003
	(0.01)	(0.02)	(0.01)
3rd tercile wealth	0.004	0.000	0.017*
	(0.01)	(0.02)	(0.01)
Nr. observations	3,694	3,694	3,694
R^2	-0.010	0.015	0.038
Kleibergen-Paap LM P-val	0.0	0.0	0.0
Cragg-Donald Wald F	97.4	97.4	97.4

Note: Standard errors in parenthesis are clustered at household level. The negative rainfall anomaly is a binary variable indicating if SPI is lower than -1.28. Time dummies are included in the specification. Significant coefficients are denoted with stars as follows: *** p<0.01, ** p<0.05, and * p<0.1.

5.1 Discussion of Results

The difference between OLS and IV results in our study can be interpreted by the attenuation bias. The coefficient of the severe constraints in the OLS is 0.054 while in the second stage of IV 0.229. Attenuation bias, also called regression dilution, is a bias in model coefficients caused by measurement error or noise in the independent variables. These errors in the independent variable bias the linear regression slope towards zero.

Moreover, our results should be interpreted with prudence, especially regarding the exclusion restriction. This caution is due to the fact that we cannot formally test the exclusion restriction but by controlling for present climate we account for temporal correlation of weather conditions. Past climate events can influence income-generating decisions, and risk aversion regarding weather, which later on can influence migration decisions. Another cautious aspect is regarding our sample, which might already be downsized. Considering we have only 6 years of data in our study, people might have already migrated and we are left with a sample of people that are not willing to move.

Moreover, our study comes with limits that future and better datasets might eliminate. Future research can aim at more precise data on soil quality like precise chemical components that shed light on how they exactly affect productivity in agriculture. There is also a need for a longer time span of the data. We have only 3 years, but land degradation happens more slowly over time, which leads to a need for a longer timeframe. Another limit is the definition of migration, where 6 months is arbitrary. With the data we have, the results we show are actually an underestimation of the effects. Land degradation is a slow effect, where many people have already migrated throughout the years that the land degraded, leaving a downsized sample in the dataset. Furthermore, it would be valuable checking in what activities people are involved in after they migrate, if they continue working in agricultural activities in a better land quality plot, or if they shift to another activity. With the data that we have available, we are limited and cannot analyze it not knowing the destination area. Future studies, if data allows, should consider checking it.

6 Robustness checks

This section is organized as follows: We first run a set of robustness checks concerning how soil health measures are defined. In particular, we use another measure for soil constraints faced by farmers. We focus on the soil workability features of the land that is measured similarly to our baseline definition, the availability of nutrients in the soil.

We then discuss the underlying mechanisms behind our results. In a reduced-form estimation framework, we show that poor soil quality (soil with difficulty of workability) contributes to lower agricultural yields. In this sense, poor health of soil drives within households migration, as a way to adapt to soil degradation, which leads to income losses.

6.1 Soil quality measured as ease of tillage

One should consider soil workability as ease of tillage that depends on the different soil characteristics. The ease of working with a particular parcel with a given soil quality depends on its characteristics, such as texture, organic matter, and stones on the profile (for an in-depth discussion, see Appendix C). Such characteristics influence the ease of using labor and machines in the field which have an incidence on yields. Similarly, we construct a dummy variable indicating whether a soil plot has severe workability constraints and re-estimate our main equation. We account for the endogeneity of soil health as farmers' past decisions and activities could contribute or control to the present state of soil quality. We employ the same 2SLS strategy, whose results are presented in Tables 4 and 5.

Our previous findings are consistent across the different specifications. On the other, hand we do not consider indicators like slope, elevation, and tropical wetness index as they are fixed features that do not unfold details about the quality and composition of the land, but they are implicitly accounted for in the soil indicators used in the present paper. Moreover, we do not consider population density which is also a popular measure in the literature. The drawback of the way population density is measured is that it is invariable over time as it is based on the 2009 Malawi Census data.

Table 4 – First Stage Results: Past Climate as IV

	sq71_d Severe constraint: soil workability
Average number of climate events 15 years ago	0.986***
	(0.10)
Negative rainfall shock	-0.026
	(0.02)
Education of HH head	0.002
	(0.00)
Age of HH head	-0.001***
	(0.00)
Female HH head	-0.016
	(0.02)
HH size	-0.014***
	(0.00)
HH is credit constrained	-0.010
	(0.01)
Urban HH	0.172***
	(0.01)
2nd tercile wealth	0.014
	(0.02)
3rd tercile wealth	0.088***
	(0.02)
	(0.02)
Nr. observations	3,694

Note: Standard errors in parenthesis are clustered at household level. The negative rainfall anomaly is a binary variable indicating if SPI is lower than -1.28. Time dummies are included in the specification. Significant coefficients are denoted with stars as follows: *** p<0.01, ** p<0.05, and * p<0.1.

Table 5 – Second Stage: the impact of workability constraint of different forms of migration

	(1) HH has a migrant	(2) Number of HH migrants	(3) Resettlement > 10km
Severe workability constraints	0.139**	0.118	0.015
	(0.06)	(0.11)	(0.05)
Negative rainfall shock	0.034**	0.044*	0.003
	(0.01)	(0.03)	(0.01)
Education of HH head	0.002	0.003	0.003***
	(0.00)	(0.00)	(0.00)
Age of HH head	0.000	0.000	-0.001***
	(0.00)	(0.00)	(0.00)
Female HH head	0.032***	0.071***	-0.003
	(0.01)	(0.02)	(0.01)
HH size	0.012***	0.025***	-0.000
	(0.00)	(0.00)	(0.00)
HH is credit constrained	-0.011	0.000	-0.001
	(0.01)	(0.01)	(0.01)
Urban HH	-0.021	-0.006	-0.013
	(0.02)	(0.03)	(0.01)
2nd tercile wealth	0.004	0.015	-0.003
	(0.01)	(0.02)	(0.01)
3rd tercile wealth	-0.005	-0.004	0.013
	(0.01)	(0.02)	(0.01)
Nr. observations	3,694	3,694	3,694
R^2	-0.031	0.011	0.037
Kleibergen-Paap LM P-val	0.0	0.0	0.0
Cragg-Donald Wald F	101.1	101.1	101.1

Note: Standard errors in parenthesis are clustered at household level. The negative rainfall anomaly is a binary variable indicating if SPI is lower than -1.28. Time dummies are included in the specification. Significant coefficients are denoted with stars as follows: *** $p<0.01$, ** $p<0.05$, and * $p<0.1$.

6.2 Agricultural Productivity

The underlying mechanism of why one would expect soil degradation to act as a push factor for individual and household migration is via its negative incidence on farm income. In this section, we attempt at verifying whether the intuition holds for the farmers included in our sample. The first challenge is to quantify production for farmers that are engaged in subsistence agriculture. The literature has identified problems of measurement errors and recall bias in survey data when farmers are asked to provide subjective evaluation of the quantity they produced, used for selfconsumption, or sold at the local markets (Eitzinger *et al.*, 2018, Methorstab *et al.*, 2017). In addition to production measurements, land size is often subject to similar biases (Dillon *et al.*, 2016, Dillon and Nagraj Rao, 2018).

We have two types of production information depending on the timing of the interview with the respect to the agricultural calendar. If the harvesting period did not occur or finish prior to the interview, farmers provide information on the expected yields. In the other case, if the agricultural season is over, then data on effective production is provided.[25] We make use of both types of data. As farmers produce a crop portfolio, one needs prices to evaluate the overall agricultural yields. Part of the farmer's agricultural production is used for consumption, and part of it is sold. The dataset we use contains information on the value of the quantities sold, which allows us to compute prices for different crops. To reduce recall bias, we use average crop prices at the community level.[26] Agricultural yields include both self-consumed and sold quantities per operated acre of land evaluated at community price levels (Malawian Kwacha (MWK)) per acre.

Further, we model yields as a function of land quality, operated land size, and other agricultural inputs fertilizer use, both organic and inorganic, pesticide use, livestock use in tropical livestock units (TLU) and labor in the total number of days worked on the farm by all the adults belonging to a given household, maximal temperature and total precipitation level in mm within the agricultural season of the current year. Rainfall intensity and temperature count as agricultural inputs in economies where irrigation systems are absent (Torres *et al.*, 2019). The results of the estimation of expected and effective yields are presented in Table 7.

Intuitively, operating in an environment with severe soil nutrient constraints reduces on average the effective agricultural yields by 200760 MWK per hectare compared to farmers that do not face such constraints.[27] This impact is statistically significant at the five percent level and economically important as it represents about 50 percent of the average sample yield. It is therefore natural to expect that farmers who are dealing with soil constraints might opt for moving away as searching of better economic opportunities. The difference in terms of expected yield in between farmers facing severe soil constraints and those who do not is statistically insignificant. Concerning the standard agricultural inputs, as expected using fertilizer increases effective agricultural yields by 280084 MWK/hectare whereas an increase of one degree Celsius in the maximal temperature, decreases effective productivity by 55818 MWK/hectare.

Regarding expected yields, the maximal temperature has a consistent detrimental effect, however

25. In some cases, depending on the timing of the agricultural season, farmers could provide both types of information.
26. If the data regarding price information are missing at the village level, then we use the national level as a reference. We can also have different types of the same category of product (for example: different types of maize). We proceed by aggregating them under one category, in this case, 'maize'. In particular, we aggregate the production for the following product categories: maize, tobacco, groundnut, and rice.
27. This value corresponds to around 195 euros/hectare

current livestock, and precipitation intensity slightly reduce expected yields. One additional day of agricultural work increases expected yields by 26.6 MWK/hectare, whereas the effect is insignificant for effective yields. The differences between effective and expected yields as well as the slight counter-intuitive effects of precipitation and livestock could result from the following potential explanations: First, yields are highly volatile therefore it might be difficult for farmers to evaluate well-expected outcomes. Second, the timing of the season when farmers are interviewed might have an influence on the estimation of future outcomes. Third, the sample we use contains missing values both for RHS and LHS variables. Therefore, interpretations of the different findings should be considered with caution.

Table 6 – The impact of soil nutrient constraint on yield

	(1) Effective yield	(2) Expected yield
Fertilizer	280084.066**	10242.001
	(131507.95)	(31128.24)
Pesticides	317012.555	111249.794*
	(268117.38)	(60813.42)
Ag. labor in days	9.005	26.674*
	(18.33)	(13.75)
TLU	10946.539	-1203.024
	(12452.19)	(1217.29)
Season precipitations	-391.966	-195.348
	(376.93)	(119.06)
Season max temperature	-55818.757	-16674.843
	(35680.87)	(12224.75)
Severe constraint: soil nutrients	-200760.799**	16087.941
	(90934.04)	(51482.47)
Obs.	2,817	2,817
R^2	0.022	0.025

Note: Significant coefficients are denoted with stars as follows: *** $p<0.01$, ** $p<0.05$, and * $p<0.1$.

7 Concluding Remarks

In this paper, we examine the intensive and extensive margin that land degradation has on internal migration and household resettlement. Our study shows how trends in rainfall affect soil quality indicators, which later on have an effect on migration. The results have important implications for internal migration dynamics given that climate change is expected to worsen, thereby threatening agricultural livelihoods, especially in risk-prone areas. We find that slow onset land degradation affects internal migration. We provide these results by first showing how climate change affects soil quality, and then secondly how soil quality affects migration.

In this study, we also focused on the climate acting through its effect on agricultural productivity yields. These results have important implications for future studies of migration streams and the relationships between migration, usage of the land, and the environment. This analysis of environmental effects on migration supports the overall importance of environmental factors by considering agricultural productivity as a push or pull factor for internal migration. It also suggests that environmental factors influence migration through multiple pathways. These results complement the existing findings that suggest an influential role of climate change on migration.

Migration and environmental policies are interlinked and cannot be optimally designed without their effects on one another being taken into account. Therefore our study aims in adding new information and results on environmental policies. It is important to note that future climatic change can be understood as an ongoing process rather than a permanent shock.

Previous literature proposes mitigation and adaptation as possible ways of dealing with climate change. We consider adaptation as an uncertain step for the following reason. There are regions that are already extremely poor and vulnerable and when climate change affects them, they are unable to adapt. As a result, unless in the presence of a poverty trap, the only solution is to move away from those areas and find areas with better living and working conditions. Given the uncertainty over adaptation, and the spread of income risk or remittances, the estimation of climate change effects on the economy and migrations is not precise. The results do, however, provide clear guidance on the link between global climate change, land productivity, and migration.

Soil degradation plays an increasingly important role in the present and future of agriculture, given the prospect of global warming. Although the underlying soil quality/migration relationship is complex and the evidence is sometimes indirect, there is a need not only in forecasts to prepare for future immigration flows in response to land degradation but also on tackling the right determinants.

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A The inter-link between migration and environmental changes

In the 1970s, Lester Brown of the Worldwatch Institute popularized the idea of environmental refugees. It was originally used in a document titled "Environmental Refugees" published by the United Nations Environment Programme in 1985. A forced environmental migrant is someone who has no choice but to leave their home due to an environmental stressor, as opposed to an environmentally motivated migrant, who may choose to migrate as a result of an environmental stressor.

There are different types of migration of interest for studying the environment-migration nexus. They include internal versus international migration, rural-rural versus rural-urban migration, and temporal versus permanent migration. We focus on the internal movement of people only. Internal migration occurs within a given country by crossing sub-national boundaries (for example, by moving between districts or provinces), different from international migration which involves crossing national borders. There is a gap in the studies that link internal migration flows with slow environmental changes. For this reason, we try to link them by analyzing possible responses of SSA crops to climate change. Roughly 17 percent of GDP was derived from agriculture in Sub-Saharan Africa, with this fraction in excess of 50 percent in some countries (World-Bank, 2009). Climatic factors affect economically relevant outcomes, agricultural output, economic growth, health, and conflict, thus a careful understanding of such effects may be essential to the effective design of contemporary economic policies and institutions (Dell *et al.*, 2014). Changes in crop yields, and water scarcity that result from climate changes occur over broad geographical areas and are likely to lead to long-term population shifts. This is different from climate processes such as sea-level rise, salinization of agricultural land, desertification and growing water scarcity, and climate events such as flooding, storms, and glacial lake outburst floods, which happen in specific areas. Crop yields in agriculture are especially relevant to developing countries, that typically have large rural populations that derive a living directly from agriculture. The ability to migrate is a function of mobility and resources (both financial and social). In other words, the people most vulnerable to climate change are not necessarily the ones most likely to migrate. The decision to migrate varies widely and deciding causality between economic 'pull' and environmental 'push' is often highly subjective. Moreover, dis-aggregating the role of climate change from other environmental, economic and social factors requires an ambitious analytical step into the dark. By interacting with and aggravating already-existing issues with food security, water shortages, and the productivity of lands, climate change puts a strain on the ability of many diverse groups to adapt. When the land can no longer support livelihoods, people are compelled to move to places with better prospects.

Sudden shocks like floods, hurricanes, rainfall, and temperature anomalies are environmental factors that are exogenous to the individual or the household making the migration decision. They can have major destructive effects as well and migration is seen as a potential adaptation strategy to environmental changes. Degradation of forests and loss of biodiversity, soil erosion, and water quality degradation are endogenous environmental changes and can have economic and social origins. They can be caused by misuse of resources, poor planning, poor infrastructure, and poor governance and monitoring. This mismanagement of resources, over-exploitation from mass industry, and industrial pollution affect climate change (change in rainfall patterns, sea-level rise, increased frequency of heat waves, and so forth, depending on location) it can be foreseen that more of the global population will be facing environmental stresses in the future, whose direct drivers are climate change, nutrient pollution, land conversion leading to habitat change, over-exploitation, and invasive species and diseases, indirect drivers to be demographic, economic, socio-political, scientific, technological, cultural and religious factors. (Millennium Ecosystem Assessment (MA), Millock (2015).

B Climate Change and environment

B.1 Climate change

Climate is usually described in terms of the mean and variability of temperature, precipitation, and wind over a period of time, which ranges from months to millions of years. Gutmann *et al.* (2005) find evidence of temperature and rainfall deviations acting as push factors for migration in the US Great Plains counties during the 1930s and the combined 1950s and 1960s. For this reason, we consider rainfall data. Drought is a natural phenomenon associated with a deficit of water availability resulting from low precipitation compared to long-term average. Drought has become more frequent and severe in arid and semi-arid lands (ASALS) than in humid areas. Drought is a disaster that affects large areas and for a longer period compared to other natural disasters such as floods. [28]

We extract rainfall data from the Africa Rainfall Climatology version 2 (ARC2), a project of the National Oceanic and Atmospheric Administration's Climate Prediction Centre (NOAA-CPP). For the period January 1983-July 2013, ARC2 delivers public re-elaborated data on the amount of rain decreasing over 10-day intervals with a spatial resolution of 0.1 degrees. Data on the maximum, minimum, and average temperature are delivered with a spatial resolution of 0.25 degrees from the European Centre for Medium-Range Weather Forecast (ECMWF). They provide two databases

28. Rainfall variability at a time scale from years to days is as much a characteristic of climate as the total amounts recorded. Low values, however, do not necessarily lead to drought, nor is drought necessarily associated with low rainfall Gommes and Petrassi (1996). The meteorological drought is associated with long time intervals of significantly low or no precipitation and increased air temperature. The deficiency in rainfall leads to low infiltration, decreased runoff, and groundwater recharge.

both recording temperature with a time resolution of 10 days. SPI data shows observed precipitation as a standardized departure from a selected probability distribution function that models the raw precipitation data. The raw precipitation data are typically fitted to a gamma or a Pearson Type III distribution, and then transformed to a normal distribution. The SPI values can be interpreted as the number of standard deviations by which the observed anomaly deviates from the long-term mean. The SPI can be created for differing periods of 1-to-36 months, using monthly input data.[29] In Figure 9 we show deviation in precipitation (SPI Index).

B.2 The link between climate change and environment

Agricultural systems face new challenges from climate change, through increased frequencies and severity of extreme events such as droughts and intense precipitation, as well as shifts in the temporal distribution of rainfalls. Vulnerable populations in developing countries are particularly exposed to financial and technical dangers due to insufficient capacities to manage climate risks (IPCC, 2014). Lacking resources to adapt, developing countries are also the most vulnerable to future warming (World-Bank, 2009). According to Barrios *et al.* (2006), agricultural drought occurs when the water supply is insufficient to cover crop or livestock water. In addition to reduced rainfall, several factors may lead to agricultural drought, some of them not always obvious. This "invisible" agricultural drought prevents farmers at the subsistence level from achieving regular and high yields. "Invisible" drought is brought about by environmental degradation as much as by climate requirements. The African continent has a long history of rainfall fluctuations of varying lengths and intensities.

When determining whether a change in the local climate will cause people to move, it is important to take into account several variables, including the type of climatic shock, the characteristics of the population affected, the various socioeconomic implications, and the availability of alternative coping mechanisms. Increasing greenhouse gas emissions brought on by human activities are the primary reason for the Earth's climate is changing fast. The "poorest nations" will be particularly heavily struck by climate change, and millions may be driven even farther into poverty (Stern, 2006). Focusing on the driving force behind environmental migration can greatly benefit policymaking. Climate change presents many critical challenges to humankind, one of them being the displacement of large numbers of people. The prospect of global mass migration induced by climate change in Stern (2006) is predicted 200 million 'environmental migrants' or 'climate refugees'. Growth and development may be seriously impacted by climate change. Especially in Africa, the development difficulties of providing food security and alleviating poverty will be considerably exacerbated by the effects of climate change on agriculture. Particularly in comparison to the industrialized world, Sub-Saharan Africa will be far more sensitive to slow-onset climate

29. Hayes et al, An evaluation of the standardized precipitation index, 2010

change and increasing climatic variability (Thornton *et al.*, 2009).

B.3 Environmental policies

Sudden climate migration could exacerbate a range of problems, including deterioration of ecosystems, slowing of regional economic development, and increased internal or international conflicts (Gleditsch *et al.*, 2007). The current estimates from IPCC (2014) suggest that a temperature increase of 2-3 degrees Celsius will potentially raise the number of people at risk of hunger by 30-200 million. Varieties with greater drought and heat tolerance, improved and expanded irrigation systems, rainwater harvesting technologies, disaster relief efforts, and insurance programs will likely all be needed to foster agricultural development and adaptation to warming. The existing theoretical and empirical research makes clear that migration is only one of several potential strategies used by households to cope with environmental change. The use of migration as an adaptation strategy depends on the frequency of exposure to droughts and the existence or not of public policy aimed at reducing the risk of a disaster or assistance after the event. Many authors have discussed the potential for environmental degradation to displace 'environmental refugees', with some estimating the number of those displaced in millions (Myers (2002), Hugo (1996), Westing (1992)). Climate change influences soil moisture levels by direct climatic effects (precipitation, temperature effects on evaporation), climate-induced changes in vegetation, plant growth rates, rates of soil water extraction by plants, and the effect of enhanced CO_2 levels on plant transpiration. Changes in soil water fluxes may also feed back to the climate itself and even may contribute to drought conditions by decreasing available moisture, altering circulation patterns, and increasing air temperatures. The drivers of climate change such as moisture, temperature, and CO_2 are expected to have variable effects on various soil processes and properties having relevance to soil fertility and productivity. Policies that take into account and put a stop to systems and processes that degrade the climate and environment are the adequate ones to be proposed.

C Plot Variables Description

C.1 Subjective Land Quality

Land quality is the ability of the land to perform its function of sustainable agriculture production and enable it to respond to sustainable land management. Some of the indicators in the LSMS Malawi dataset, that help understand the quality of land are slope, elevation, total wetness level and index and fallowness.

We calculate subjective land quality in a survey where respondents have different size parcels. Thus we create weights for their size. This weight is the size of the plot out of total sum of parcels. We have both subjective answer from farmers and objective data from satellites. In cases when farmers do not know the size of their parcel, we consider the gps satellite size. We multiply the weights that we constructed, with the perceived quality of lands, in order to have a weighted quality of land measure. We take the mean value of the land quality of all parcels of the household. We do this for the wet and the dry season, years 2010, 2013 and 2016. For the permanent crops there is data only for 2010 and 2013 and there is no subjective quality of land indicator.
We keep only the rainy season since it is the main one and also because there are not all the indicators in the dry season (support it with literature). Their irrigation system lies only on the rain and not water reserves. These subjective data often aim at capturing the overall soil quality level (in a categorical manner) as well as key soil quality indicators, such as soil color and texture. One might assume that respondents who spend ample time working on the land would be able to assess the health of the soil with reasonable accuracy. Soil health, however, is a highly complex subject, and this assumption can be misguided.[30] The objective land quality uses geo plot variables provided from the world bank but collected from other satellite data sources for the year 2013 and 2016. We consider elevation, slope and total wetness index as indicators of land quality. We construct variables of these indicators according to the weight of the parcel index. We then sum up all the indexed parcels.

C.2 Objective Land Quality

The absence of regular, high-quality data on soil health and how it is evolving under previous and present management has a significant impact on the study of agricultural production that is

30. Several factors that might affect the credibility of subjective results are: a) subjective assessments of soil health should be provided at the plot level rather than farm level b) appropriate respondent(s) may not be available to answer questions during the time that the survey team or the enumerator will be visiting the associated enumeration area (EA), the use of proxy respondents will be one of the factors mediating the reliability of the information sought. c) in rural areas where mobility is limited, a respondent's reference is only the soil in and around his or her farm. d) It may not be clear to respondents that the intention is to isolate the quality of the soil itself and not other plot characteristics or production outcomes. Source: LSMS guidebook, Spectral Soil Analysis & Household Surveys from S.Gourlay, E. Aynekulu, C. Carletto, and K.Shepherd, World Bank

currently being done. We utilize the Harmonized World Soil Database (HWSD), a 30 arc-second raster database that contains over 15000 distinct soil mapping units and incorporates global regional and national updates of soil information from the European Soil Database, SOTER, Soil Map of China, and WISE. Utilizing a standardized structure, they may link attribute data with GIS to display or query the composition in terms of soil units and the characterization of certain soil parameters (organic Carbon, pH, water storage capacity, soil depth, cation exchange capacity of the soil and the clay fraction, total exchangeable nutrients, lime and gypsum contents, sodium exchange percentage, salinity, textural class and granulometry).

Traditional wet chemistry techniques for soil nutrient extraction are part of conventional soil analysis, which is regarded as the gold standard in soil testing. Basic physical analysis, such as the determination of water-holding capacity, is also included. The Mehlich 3 extractant technique is among the most used methods for extracting nutrients in conventional wet chemistry. Micronutrient and macronutrient levels are estimated using the Mehlich 3 technique.[31]

We use as indicators of soil quality the following: [32] and uses parameter scale from 0 to 100% divided in 'no or slight constraint', 'moderate constraint', 'severe constraint', 'very severe constraint', 'not suitable'. The rating system is adapted from Sys et al[33] The indicators are the following:[34] 1. Nutrient availability: Soil texture, soil organic carbon, soil pH, total exchangeable bases
2. Nutrient retention capacity: Soil Organic carbon, Soil texture, base saturation, cation exchange capacity of soil and of clay fraction
3. Rooting conditions: Soil textures, bulk density, coarse fragments, vertic soil properties and soil phases affecting root penetration and soil depth and soil volume
4. Oxygen availability to roots: Soil drainage and soil phases affecting soil drainage
5. Excess salts: Soil salinity, soil sodicity and soil phases influencing salt conditions
6. Toxicity: Calcium carbonate and gypsum
7. Workability (constraining field management): Soil texture, effective soil depth/volume, and soil phases constraining soil management (soil depth, rock outcrop, stoniness, gravel/concretions and hardpans).[35] [36]

For analyzing soil qualities, maize was selected as reference crop because of its global importance and wide geographical distribution. In the table 1 below, all the indicators of land quality we use

31. Mehlich, 1984
32. The classes used in the Soil Quality evaluation are: 1. No or slight limitations, 2. Moderate limitations, 3. Sever limitations, 4. Very severe limitations, 5. Mainly non-soil, 6. Permafrost area, 7. Water bodies.
Classes 1 to 4 are corresponding to an assessment of soil limitations for plant growth. Class 1 is generally rated between 80 and 100% of the growth potential, class 2 between 60 and 80%, class 3 between 40 and 60%, and class 4 less than 40%.
33. Sys, C., Van Ranst, E., Debaveye, Ir.J Beernaert, F. 1993. Land evaluation, part III. Crop requirements. Agriculture publication, no.7, General Administration for Development Cooperation. Brussels, Belgium, 166p.
34. Source: Food and Agriculture Organization and Harmonized World Soil Database
35. More details to follow up in Appendix D
36. Source: FAO, Food and Agriculture Organization

in our study.

Table 7 – Land quality indicators

Subjective Land Quality	Data declared from respondents of LSMS Malawi where they describe the quality of their land as good, fair and poor by using the numbers 1, 2 and 3. The higher the index, the worst the land quality.
Slope	The topography of a field greatly determines how sensitive the soil is to water erosion. The steeper and longer the slopes are in a field, the greater the soil erosion potential. In comparison to a mild slope, a steep slope will have a higher effect on the soil's composition. Organic particles rich in nutrients from the topsoil will flow down the slope as rain falls. When vegetation is limited and water levels rise, this occurs more frequently. The slope's angle toward the sun affects the soil as well but we do not have data on that. Slope <8 percent is good, 8-15 medium, 15-25 poor [37]
Elevation	Higher altitude is associated to lower temperatures which further decreases the mineral rate. This can reduce litter decay, soil organic matter (SOM) decomposition rates, soil water balance and geologic deposition processes. Moreover, variation in soil properties due to topography contributes to soil physical, biological and chemical quality variations at different elevation categories. [38]
Topographic wetness index	It is constructed to predict the spatial distribution of soil moisture and surface saturation as well as to assess the impact of local topography on hydrological processes. This index is formulated as TWI = ln(a/tanb), where 'a' is the upslope contributing area per unit contour length (or Specific Catchment Area, SCA) and 'tanb' is the local slope gradient for estimating a hydraulic gradient. The computation of both 'a' and 'tanb' need to reflect impacts of local terrain on local drainage. TWI is an indicator that measures the potential on where water tend to accumulate. A high index value denotes high potential of water accumulated due to low slope.[39]

37. *Schiefer et al 2015*Indicators for the definition of land quality as a basis for the sustainable intensification of agricultural production
38. *Fantaw et al., 2006b; Jing et al., 2011; Asmamaw and Mohammed, 2012*
39. *Qin et al 2009*, An approach to computing topographic wetness index based on maximum downslope gradient

Nutrient availability (SQ1)	This soil quality is decisive for successful low level input farming and also for intermediate input levels. Diagnostics related to nutrient availability are manifold. Important soil characteristics of the topsoil (0-30 cm) are: Texture/Structure, Organic Carbon (OC), pH and Total Exchangeable Bases (TEB). For the subsoil (30-100 cm), the most important characteristics considered are: Texture/Structure, pH and TEB. The soil characteristics relevant to soil nutrient availability are to some extent correlated. For this reason, the most limiting soil characteristic is combined in the evaluation with the average of the remaining less limiting soil characteristics to represent soil quality SQ1. [40] [41]
Nutrient retention capacity (SQ2)	Nutrient retention capacity is of particular importance for the effectiveness of fertilizer applications and is of special relevance for intermediate and high input level cropping conditions. The ability of the soil to hold onto more nutrients against leaching-related nutrient losses is referred to as "nutrient retention capacity." Plant nutrients are stored in the soil by the clay fraction, organic matter, and clay-humus complex, which offer exchange sites. The amount of leaching varies depending on the pace at which soil moisture drains through the soil profile. Through its impacts on the accessible exchange sites on the clay minerals and through soil permeability, soil texture influences nutrient retention capacity in two ways. The soil characteristics used for topsoil are respectively: Organic Carbon (OC), Soil Texture (Text), Base Saturation (BS), Cation Exchange Capacity of soil (CECsoil), pH, and Cation Exchange Capacity of clay fraction (CEC-clay). Soil pH serves as indicator for aluminum toxicity and for micro-nutrient deficiencies. The most limiting of these soil characteristic is combined with the average of the remaining less limiting soil characteristics to estimate nutrient retention capacity SQ2. Source of information in footnote 40 and 41.

40. Soil Qualities for Crop Production from Food and Agriculture Organization of the United Nations
41. Fischer, G., F. Nachtergaele, S. Prieler, H.T. van Velthuizen, L. Verelst, D. Wiberg, 2008. Global Agro-ecological Zones Assessment for Agriculture (GAEZ 2008). IIASA, Laxenburg, Austria and FAO, Rome, Italy.

Rooting conditions (SQ3)	Rooting conditions include effective soil depth (cm) and effective soil volume (vol. %) related to presence of gravel and stoniness. The presence of a soil phase may alter rooting conditions by reducing the effective volume available for root penetration or by restricting the effective rooting depth. Rooting conditions discuss numerous connections between crop development and soil conditions in the rooting zone. The assessment takes into account the following variables: Adequate foothold, or enough soil depth for the crop to anchor; available soil volume and penetrability for roots to extract nutrients; space for root and tuber crops to expand and produce an economically viable amount of crop in the soil; and absence of shrinking and swelling properties (vertic) affecting root and tuber crops. Root penetration is impacted by soil depth/volume restrictions, which might also limit yield production (roots and tubers). The following pertinent soil characteristics are taken into account: soil depth, soil texture/structure, vertic properties, gelic properties, petric properties, and the presence of coarse particles. This soil quality is calculated by multiplying the soil depth restriction by the most restricting attribute of the soil or soil phase. The soil phases that are important for rooting conditions vary slightly depending on the source of the soil map and the kind of soil being used. In the HWSD (FAO 74) soil phases are: stony, lithic, petric, petrocalcic, petrogypsic, petroferric, fragipan and duripan. Other soil phases are (FAO 90): rudic, lithic, pertroferric, placic, skeletic, fragipan and duripan. ESB soil phases and other soil depth/volume related characteristics: stony, lithic, petrocalcic, petroferric, fragipan and duripan, and presence of gravel or concretions, obstacles to roots (6 classes), and impermeable layers (4 classes). Source of information in footnote 40 and 41.
Oxygen availability (SQ4)	The drainage properties of soils have a key role in determining oxygen availability in soils. Based on methods established at the FAO (FAO 1995), which consider soil type, soil texture, soil phases, and terrain slope, soil drainage classes are determined. In addition to drainage parameters, soil and terrain variables may have an impact on the soil quality and oxygen availability. Source of information in footnote 40 and 41.

Excess salts (SQ5)	Salinity might be brought on by salt accumulation. Soil salinity, which is the excess of free salts, may be determined by measuring the electric conductivity (EC in dS/m) or the saturation of the exchange complex with sodium ions (sodicity or sodium alkalinity), which is determined by the exchangeable sodium percentage (ESP). Crops are impacted by salinity because it prevents the intake of water. Low salt levels may cause crop death, whereas moderate salinity diminishes yields and inhibits growth. Sodicity influences soil structure, causing vast or coarse columnar structures with limited permeability due to salt toxicity. Saline (salic) and sodic soil phase characteristics may have an impact on crop growth and yields. When both processes occur, the most restricting combination of soil salinity and/or sodicity conditions and the occurrence of saline (salic) and/or sodic soil phase is chosen. Source of information in footnote 40 and 41.
Toxicities (SQ.6)	Low pH causes different shortages, such as phosphorus and molybdenum deficiency, as well as acidity-related toxicities, such as aluminum, iron, and manganese toxicities. Calcareous soils typically have micronutrient shortages, such as those in iron, manganese, and zinc, and occasionally molybdenum toxicity. Gypsum severely restricts the moisture content of the soil. Crops' susceptibility to gypsum and calcium carbonate varies greatly.[42] High calcium carbonate and gypsum concentrations and low pH are incompatible. SQ1, nutritional availability, and SQ2, nutrient retention capacity, respectively, account for acidity-related toxicities such as aluminum toxicities and micronutrient shortages. Therefore, only toxicities associated with calcium carbonate and gypsum are included in this soil quality SQ6. For the purpose of quantifying SQ6, the excess calcium carbonate and gypsum present in the soil, as well as the presence of petrocalcic and petrogypsic soil phases, are considered to be the most restricting factors. Source of information in footnote 40 and 41.

42. FAO, 1990; Sys et al, 1993

Workability (SQ7)	Diagnostic characteristics to indicate soil workability vary by type of management applied. Workability or ease of tillage depends on a variety of interrelated soil properties, including texture, structure, organic matter content, bulk density, and the presence of gravel or stones in the soil profile or on the soil surface, as well as continuous hard rock at shallow depths and rock outcrops. Heavy agricultural equipment might not be able to be used due to irregular soil depth, gravel and stones in the profile, and rock outcrops. While soil restrictions linked to uneven soil depth and stony and rocky soil conditions are primarily effecting mechanized land preparation and harvesting operations of high-level input mechanized farming LUTs, they are also especially harming low and intermediate input farming LUTs. Therefore, workability limitations for low/intermediate and high inputs are addressed differently. The physical impediment to agriculture and the cultivation restrictions brought on the texture/clay mineralogy are both included in the workability soil quality SQ7. The most restricting soil/soil phase characteristic is combined with the average of the other attribute conditions to create the soil quality SQ7. Soil phases are stony, lithic, petric, petrocalcic, petroferric, fragipan and duripan (FAO '74), and lithic, petroferric, rudic, skeletic, duripan and fragipan (FAO '90). Source of information in footnote 40 and 41.

D Summary Statistics

E Maps

E.1 Subjective Land Quality and TWI

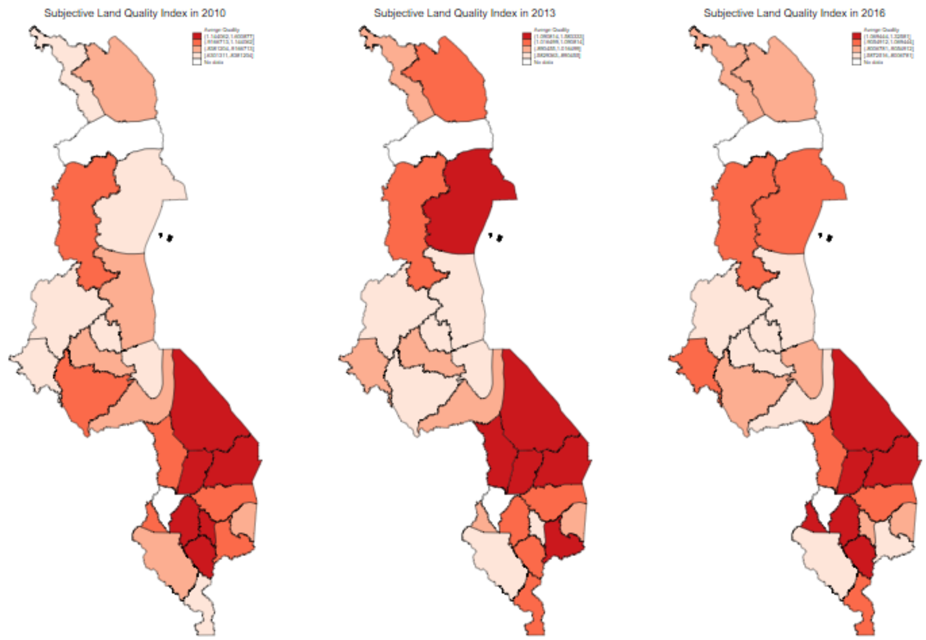
E.2 Objective land quality

E.3 Migration

E.4 Climate change

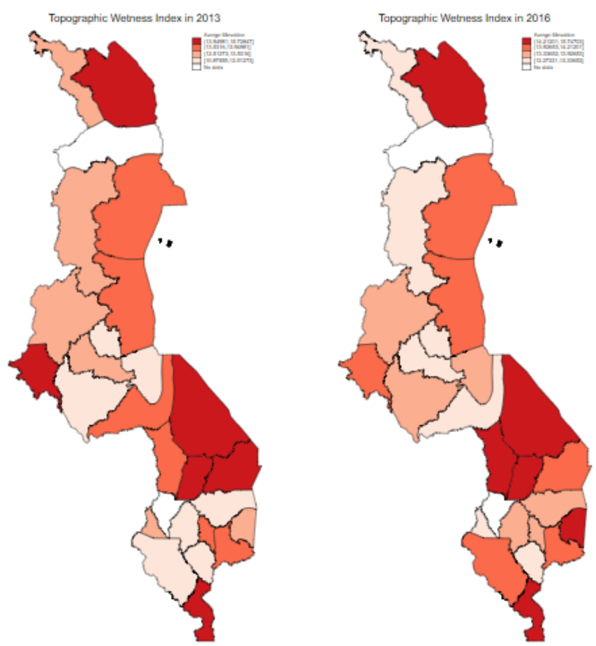
Table 8 – Summary Statistic of all variables

Label	Description	Min	Max	Mean	St.dev
migration					
migrants	Dummy where hh has a migrant that has left in the past 6 months	0	1	0.06	0.24
hhmigrant	Number of migrants per hh that left in the past 6 months	0	8	0.09	0.46
resettle	Dummy if the household has resettled since the previous wave	0	1	0.05	0.21
land specification					
landown	Land owned in hectares	0	3.67	0.56	0.5
landless	Household does not hold any land	0	1	0.08	0.27
slope	Slope of the territory where household owns land	0	47	4.5	4.7
elevation	Elevation of the territory where household owns land	0	1610	842	343
twi	Total wetness Index	0	28	13.4	3
sq1	Nutrient availability	1	7	1.64	1.45
Household characteristics					
hhsize	Household Size	1	20	5.16	2.31
urban	Dummy where household lives in an urban area	0	1	0.25	0.43
femhead	Dummy where household head is a female	0	1	0.23	0.42
agehead	Age of household head	16	113	45	15
educave	Average years of education in the family	0	18.5	5.56	2.86
hhlabor	Household members older than 14 and younger 60 years old	0	9	2.45	1.38
wealth	Non-agricultural wealth index	-0.76	12.6	0.21	1.33
agwealth	Wealth scores	-1.61	7.38	-0.01	1.02
dist	Household distance from a main road	0	46	7.75	9.34
credit	Household is credit constrained	0	1	0.56	0.5



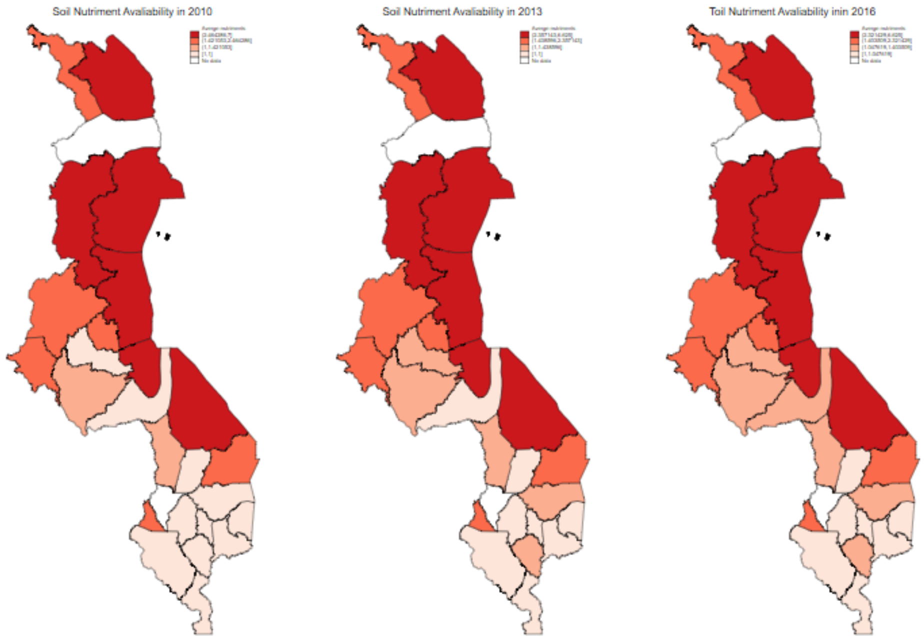
(a) 2010 (b) 2013 (c) 2016

Fig. 3 – Land quality



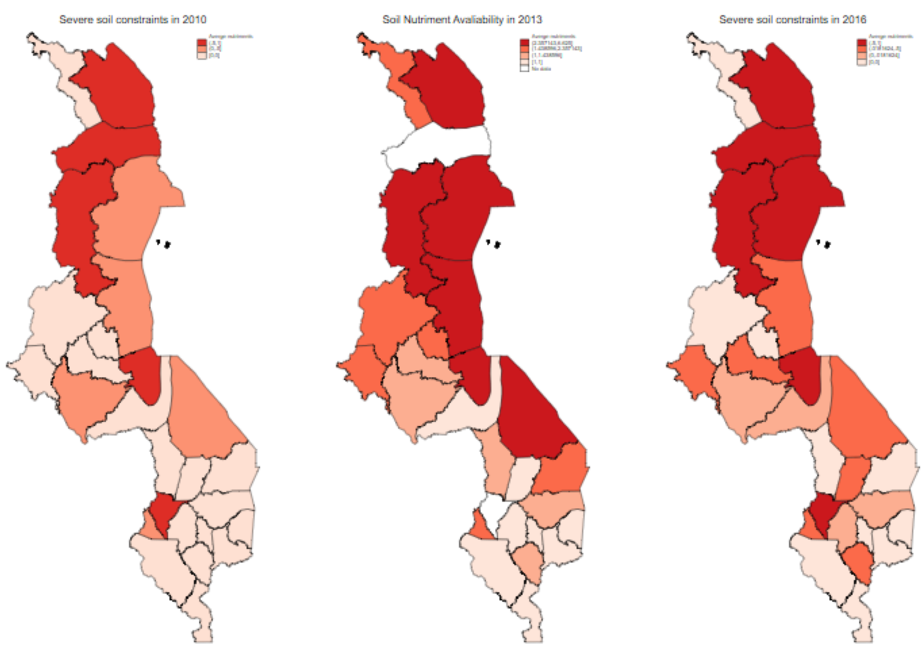
(a) 2010 (b) 2013

Fig. 4 – Total wetness index



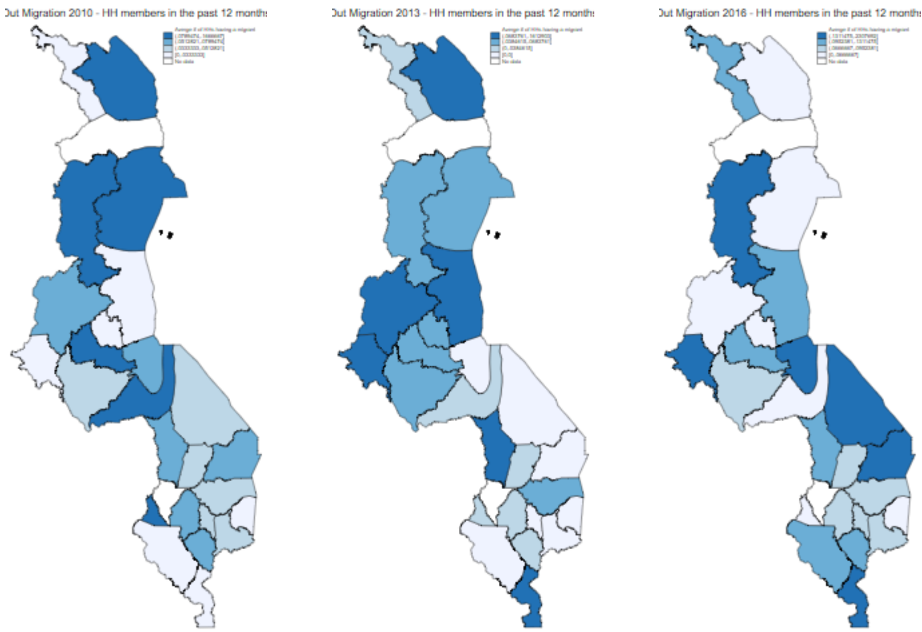
(a) 2010 (b) 2013 (c) 2016

Fig. 5 – Objective land quality (nutrient availability)



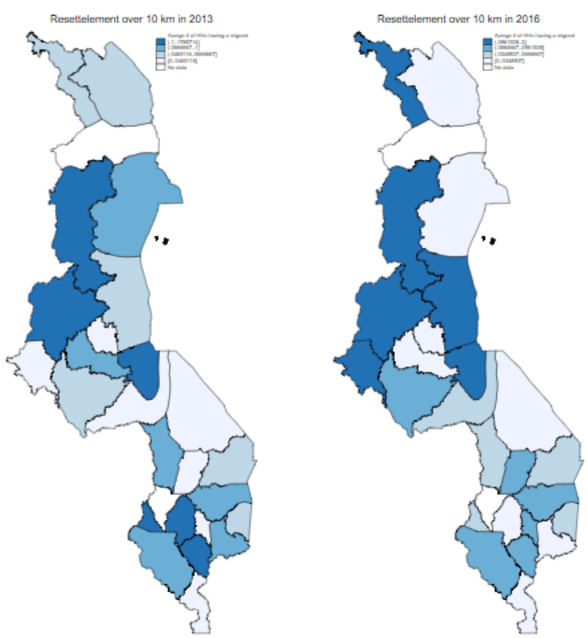
(a) 2010 (b) 2013 (c) 2013

Fig. 6 – Objective land quality (nutrient availability) dummy with 'severe' or 'not severe constraints'



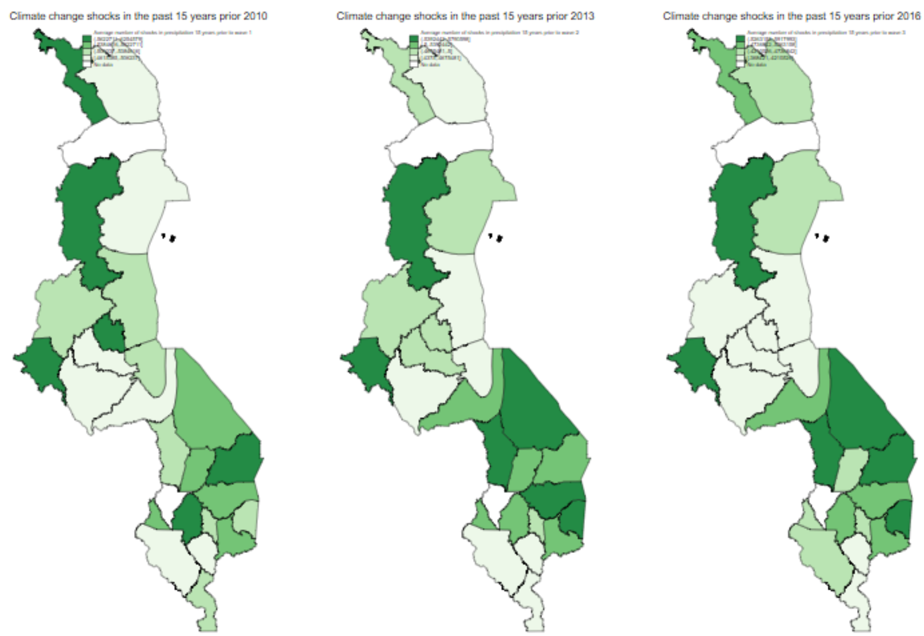
(a) 2010 (b) 2013 (c) 2016

Fig. 7 – Who left in the past 12 months



(a) 2013 (b) 2016

Fig. 8 – Resettle: households that resettled in more than 10 km



(a) 2010 (b) 2013 (c) 2016

Fig. 9 – Deviation in precipitation SPI

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