Mapping hotspots of climate change and food insecurity in the global tropics

CLIMATE
CHANGE
AGRICULTURE AND
FOOD SECURITY

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Front cover photo

By Neil Palmer (CIAT). A rice farmer in Guarayos, Santa Cruz, Bolivia, prior to a huge storm.

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Abbreviations and acronyms

CAFFS – CGIAR Research Program on Climate Change, Agriculture and Food Security

CGIAR – Consultative Group on International Agricultural Research

CV – coefficient of variability

FAO – Food and Agriculture Organization of the United Nations

FAOSTAT – FAO Statistical Database

FEWSNET – Famine Early Warning System Network

GCM – general climate model

GDP – gross domestic product

GECAFS – Global Environmental Change and Food Systems

IGP – Indo-Gangetic Plains

ILRI – International Livestock Research Institute

IPC – Integrated Food Security Phase Classification System

IPCC – Intergovernmental Panel on Climate Change

LGP – length of growing period

Lgpdelt – decrease in length of growing period (LGP).

PIN – per capita net food production index number

RCGD – reliable crop growing days

Rdaydec – rainfall per rainy day decreases

Rdayinc – rainfall per rainy day increases

SPI – standardized precipitation risk

Tgrow – maximum temperature during the growing season

Tmax – maximum temperature

Tmean – mean annual temperature

UNEP – United Nations Environment Programme

WHO – World Health Organization

WCRP – World Climate Research Program

Executive Summary

This study was coordinated by the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) to identify areas that are food insecure and vulnerable to the impacts of future climate change, across the priority regions for the CGIAR centres. The research was undertaken by a team of scientists from the International Livestock Research Institute (ILRI). The study relied on maps: first, of variables that indicate the different aspects of food security (availability, access and utilization), and second, of thresholds of climate change exposure important for agricultural systems. Vulnerability was assessed using a domain approach based upon the Intergovernmental Panel on Climate Change (IPCC) framework of vulnerability as a function of exposure, sensitivity and coping capacity. Nine domains were identified; for each domain, areas of the tropics were classified by high or low exposure, high or low sensitivity, and high or low coping capacity.

Length of growing period declines by 5% or more across a broad area of the global tropics, including heavily cropped areas of Mexico, Brazil, Southern and West Africa, the Indo-Gangetic Plains, and Southeast Asia. This suggests that at a minimum, most of the tropics will experience a change in growing conditions that will require adaptation to current agricultural systems. High temperature stress (above 30°C) will be widespread in East and Southern Africa, north and south India, Southeast Asia, northern Latin America and Central America. Length of growing period flips to less than 120 days in a number of locations across the tropics, notably in Mexico, northeast Brazil, Southern and West Africa and India. This is a critical threshold for certain crops and rangeland vegetation; hence these are important target areas for high exposure to climate change. Reliable crop growing days decrease to critical levels, below which cropping might become too risky to pursue as a major livelihood strategy in a larger number of places across the global tropics, including West Africa, East Africa, and the Indo-Gangetic Plains. Much of the tropics already experiences highly variable rainfall, above the median of 21% for cropped areas. Thus any increases in this variability will make agriculture more precarious.

In terms of food security, the net food production index is stagnant in all areas of interest, with differences between countries rather than regions. GDP per capita is low in many countries in Africa, as well as in Afghanistan, Nepal, Bangladesh, Laos and Cambodia. Poverty hotspots are West, Central and East Africa, India and Bangladesh and Southeast Asia. Africa and south Asia are clearly much more chronically food insecure regions than Latin America or China.

The most vulnerable domain for most exposures is high exposure, high sensitivity and low coping capacity (HHL). Such areas are highly vulnerable to climate change and have significant agriculture and high levels of food insecurity. Under exposure 1 (LGP decreases more than 5%), 265.7 million people are in the HHL category. For exposure 2 (LGP flips) HHL is very small in terms of people; most people are in the categories LHL or LHH. Exposure 3 (reliable crop growing days - RGCP flips) has about 14 million more people in the HHL category, but again most people are in LHL or LHH. Under exposure 4 (maximum temperature flips), the vulnerable population more than triples relative to exposure 3. Under exposure 5 (maximum temperature during the growing season flips) again more people are in the vulnerable categories. Under exposure 6 (rain per rainy day decrease), the most vulnerable population drops to 85 million, while under exposure 7 (rain per rainy day increase) 138.4 million are in the HHL category. This suggests that the choice of domain variables makes a big difference in terms of areas included.

1. Introduction

The CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) commissioned a small team of ILRI/ CCAFS Theme 5 staff to conduct a rapid assessment across the global tropics of the vulnerability of food security to climate change. The goal was to identify 'hotspot' locations where climate change impacts are projected to become increasingly severe by 2050 and food insecurity is currently a concern, using a range of indicators. The project is intended to help CCAFS by giving input to the selection of new target regions (i.e. multi-country) ex ante, and also as an ex post check of the three target regions chosen at the start of the project: East Africa, West Africa and the Indo-Gangetic Plains (IGP). In addition, the project is the start of a process that will link to regional scenarios and regional and local quantification work. Using maps as aids in the visualization of the possible impacts of climate change across the tropics and within regions will be important. This project also demonstrates the multiple indicators of food security that can be mapped and will interact with climate change. Finally, the project contributes to CCAFS work by including methods for mapping both food insecurity and the impacts of climate change on agriculture and food security, and giving guidance on interpreting results, particularly overlap, or lack of it, between the two categories of hotspots.

The work unfolded in several steps. First, a data scoping study of food security indicators was undertaken to identify both indicators of the components of food security and indicators that could be mapped from local to global level. This study also reviewed the recent debates about measuring food insecurity. Second, a workshop was held to determine which food security indicators could best be mapped. The workshop participants[1] also discussed which climate change impact indicators are available and can be mapped, and how these are relevant to food insecurity. A framework for assessing the vulnerability of food security to climate change was discussed and future work to develop this for CCAFS identified. Then both the food (in)security and the climate change impact indicators were mapped and hotspots identified. Finally we mapped nine vulnerability domains, combining exposure to climate change impacts, sensitivity to this change and coping capacity for adverse impacts on food security. All results are mapped for the entire region of interest.

[1] Alison Misselhorn, Keith Weibe, Tanya Beaudreau, Erin Lentz, Jeronim Capaldo, Jean Balie, and Mark Smulders.

Food security concepts and indicators

Definition

Food security is defined as a situation that exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life (FAO in Stamoulis and Zezza 2003). In order for a population to be characterized as food secure, they have to have enough nutritious, yet affordable food, and be sufficiently protected against future disruptions to the access of adequate food. For analytical purposes, the complex definition of food security can be broken up into three components: availability, access and utilization. A fourth dimension, stability, refers to the requirement that food secure people have access to appropriate food at all times. Ericksen (2008a) defined access, availability and utilization as shown below. Note that there is overlap among these dimensions; for example both availability and access discuss the need for equitable distribution of food and both access and utilization reflect the requirement for food secure people to have food that meets social and cultural preferences.

Food **availability** refers to the amount, type and quality of food a unit (such as community, household, individual) has at its disposal to consume. It can be further broken down into production, distribution and exchange (see Figure 1.1).

Access to food refers to the ability of a unit to obtain access to the type, quality, and quantity of food it requires. The subcomponents of access are affordability, allocation and preference.

Food **utilization** refers to the individual or household capacity to consume and benefit from food. The three subcomponents are nutritional value, food safety and social value.

Note that there is a hierarchical relationship among these three components: "food availability is necessary but not sufficient for access, and access is necessary but not sufficient for utilization" (Webb et al 2006). Thus there may be plenty of food in the markets, but if it is too expensive for people to buy then they are food insecure. Or the food that is available and affordable may be of inferior quality and hence people may be micronutrient deficient. Diseases such as HIV can also interfere with people's ability to utilize foods properly while a hazard or shock could adversely affect any one of

FOOD UTILIZATION

- Nutritional value
- Social value
- Food safety

FOOD ACCESS

- Affordability
- Allocation
- Preference

FOOD AVAILABILITY

- Production
- Distribution
- Exchange
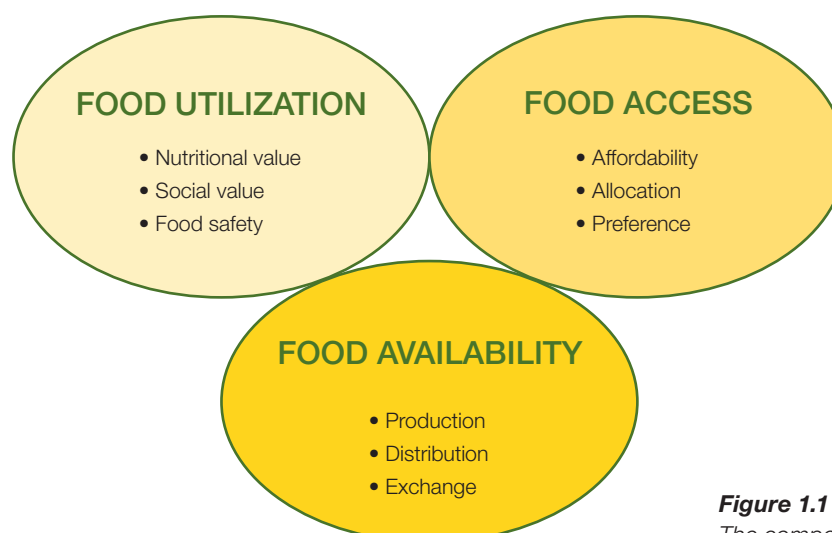
Figure 1.1
The components of food security.

these aspects (make food more expensive, cause shortfalls in production, or affect food safety); hence stability over time is also included. Food security status is also linked to a number of socio-economic characteristics, including wealth, age and status within a household. In addition, the gender dimension of food security has been explored in terms of the differences between food security outcomes for men and women in the same household and with regard to the key role that women play in attending to the food security of their children (FAO 2011).

An important distinction exists between chronic and transitory food insecurity, both in terms of indicators and underlying causes. Transitory food insecurity implies that there has been a temporary shock to food security but that the situation will return to normal after a period of time. Chronic food insecurity means people cannot meet their basic requirements for a significant period of time with a more long term outcome. The drivers of transitory and chronic food insecurity are often different: transitory results from variability in production, food prices, or incomes, while chronic is the result of systemic or structural failure such as poverty or political marginalization. The two do interact, as chronic food insecurity results from one or a series of transitory shocks causing very vulnerable households to lose the ability to cope with any future shocks. Chronic food insecurity, such as high malnutrition rates or low household incomes, can make populations much more vulnerable to severe transitory shocks like a price increase (Misselhorn et al 2010). This distinction is relevant for CCAFS because climate change will have longer term impacts on production trends but in the short term it will increase variability and extreme events. Food insecurity is always due to multiple stressors, so the impact of climatic shocks has to be in the context of this multiple exposure.

Measuring Food (In)Security

The continued refinement of the definition of food security over the past three decades in response to improved empirical evidence has brought a greater understanding of both the components and the underlying causes of food insecurity. Despite this, the measurement and evaluation of food insecurity remains difficult. For much of the 1970s there was a bias equating food security with availability; this began to change after Sen's 1981 book articulating the idea that famines are not necessarily caused by a lack of food, but a lack of access to it (Webb et al 2006). Given the acknowledged multiple dimensions of food security, one indicator does not give the entire picture. Because it is a complex concept, involving the interaction of many different factors, there is no single measurement for food security (Riely et al 1999). Multiple indicators, most of which are proxy indicators, are used to determine food security status, and these vary depending on the global, national, district, household, or individual level.

Webb et al (2006) outline three recent advances in understanding and measuring food security. The first is a shift from measuring availability and utilization to measuring "inadequate access". Researchers and policy makers are increasingly acknowledging that purchasing power is the key to access. This shift happened after research showed a weak relationship between food availability and nutritional status, at national, household and individual levels. While the shift to measuring access is a crucial development to better understanding food insecurity, there are no exact indicators of access failure. Widely accepted proxies of both food supply failure and impaired utilization are available, but the relatively new attempt to measure inadequate access is not as yet developed. Households have many ways to mitigate or cope with negative shock and the search for measures

of access failure has recently focused on measuring the potential use of these coping behaviours as indicators (Coates et al 2006).

The second shift in food security measurement is an expanding effort to find fundamental measures instead of relying on proxy measures. Much of the food security measurement that takes place in developing countries is 'derived measurement', which relies on proxy measures such as food consumption, income, or assets - thought to be indicators of food security. This is problematic because:

- There is no empirical link between the measures and actual food insecurity.

- The strength of correlation may differ between contexts and causes and consequences may also differ.

- The actual causes and consequences of food insecurity may be overlooked when using derived measures.

However proxy measures are often all there are to use, given the absence of fundamental measures (Webb et al 2006).

The third shift identified by Webb et al (2006) is a shift from focusing on objective to subjective measures: moving away from absolute measures, such as poverty lines and expenditure on goods and services, to experiential and perception measures that can be analyzed using econometric methods. For example, Coates et al (2006) analyse 22 separate scales and ethnographies exploring food insecurity and find four universal domains: uncertainty or worry, insufficient quantity, inadequate quality and social unacceptability. The first and last of these are subjective assessments but are fundamental to the experience of food insecurity.

In addition to being complex, measuring food security is time consuming and it is expensive to gather data at individual and household levels. Availability estimates can be generated at relatively low cost, especially at national and global scales, but they hide the difficult aspect of understanding access and utilization patterns at household and individual levels; for example differences between males and females, young and old. "The global figures mask considerable heterogeneity among and within regions. … Food security measures based on household and individual data routinely generate higher estimates of food insecurity than those derived from more aggregate data" (Barrett 2010 p.826). To fully understand food security, we must measure more than just nutritional status and availability of supply; the element of vulnerability must be captured as well (Barrett 2010). This is a difficult concept to assess. Most measures of food insecurity (such as food intake, food production or income, and nutritional status) are static in nature and do not predict the possibility of having inadequate food in the future (Christiaensen and Boisvert 2000). It is not possible from such measures to assess if those who are currently food secure will become insecure in the future or vice versa. "Observational data necessarily report on the past… An ideal food security indicator would reflect the forward-looking time series of probabilities of satisfying the access criteria" (Barrett 2010 p.826).

The problem of defining thresholds complicates the conceptual complexity of food security and its difficulties of measurement. There is little agreement on which thresholds should be used to describe the difference between food security and food insecurity, with the exception of FAO's standard of undernourishment, and perhaps the WHO growth standards for children under five (WHO 2009). Two widely applied food security classification systems, the Famine Early Warning System Network (FEWSNET) and the Integrated Food Security Phase Classification System (IPC), differ in several key aspects of classification. FEWSNET classifies food security outcomes (such as food deficits and malnutrition), but not underlying conditions (for example, poor crop production, chronic poverty, or high food prices). In contrast, the IPC takes into account underlying conditions affecting food security, such as civil strife and hazards. The IPC also sets more quantitative thresholds than FEWSNET, including crude mortality rates, acute malnutrition, stunting, caloric intake, and water availability. Also, FEWSNET colours map areas with the food security level of the majority of the poorest wealth group in a given area, while the IPC colours a region based on the highest level of food insecurity found there. A further complication is the use of stunting (low height for age) for chronic food insecurity and the use of wasting (low weight for height) for transitory or acute food insecurity. Food security responses are often based on the indicators collected, so measuring either stunting or wasting may produce different response options, either in the form of direct interventions or policies. Also for consideration in the complexity of measuring and setting thresholds for food insecurity is the issue of lagging versus early indicators. As indicated by Barrett (2010), most measures of food security are reporting on the past: nutritional indicators, whether of stunting or wasting, reflect that food insecurity has already occurred. While monitoring food prices can provide an indicator of future food insecurity to some extent, researchers are still working to find predictive indicators that can be used to design preventative measures against food insecurity, rather than learning about food insecurity once it has occurred and only then intervening to mitigate it.

A final point is the issue of level of measurement. As discussed above, referring to Barrett (2010), global food security measures are broad and hide significant disparities between regions. National indicators can offer comparability between countries, but also obscure great differences at provincial or district levels within a single country. Given the complex nature of food security, household level surveys and local studies are more suited to explain processes than global aggregate measures, but lack comparability and broad coverage. Global, national, and regional levels of production and availability figures can paint a broad view of the first pillar of food security while sub-national measures of livelihood and coping strategies offer a more detailed picture of access. Lastly, stability is not only difficult to define but also to measure, and even more difficult to predict.

To find suitable indicators to map, the project team compiled a large database of food security measures for each of the components, first at the global level, then for each of the three regions of interest for CCAFS, initially East Africa, West Africa and the Indo-Gangetic Plains, and for each country in the region. These indicators and descriptions are attached in Appendix 1. We identified indicators for access, availability and utilization, at each of the geographic levels of interest. We considered a number of indicators for stability and these are also shown, but as this requires predictive capacity, which at the moment this exercise does not include, we left this for future work. However we will include a temporal and dynamic dimension in the scenarios and modelling work.

How might climate change increase risk of food insecurity?

A unit of analysis or a system is vulnerable to an adverse shock or change if it will suffer harm from which it is difficult to recover. Vulnerability to climate change can be conceived as a function of exposure to a hazard (such as changes in temperature or precipitation from climate change), sensitivity to that hazard (for example, maize yields are highly sensitive to drought) and finally, adaptive capacity in the face of the hazard. Adaptive capacity reflects the ability of a system or

community to manage the impacts of a shock. Figure 1.2 below, illustrates these concepts for food systems. If people have sufficient assets or strategies to manage a shock without suffering harm, then they will not be vulnerable (McCarthy et al 2001).

Combining the hazard indicators with indicators of sensitivity and adaptive capacity helps to evaluate vulnerability, as exposure to changed climate patterns alone will not necessarily lead to increased vulnerability. As explained above, food insecurity is a function of multiple stressors, and climate change will add more stress, or potentially increase food insecurity if people, households or geographic areas are highly sensitive to the climate hazard and have insufficient coping capacity. Most of the measures of food (in)security collected are outcome indicators: e.g. the malnutrition rate in a community rather than the drivers or underlying processes that contribute to that malnutrition, such as chronic poverty, disease, or lack of access to diverse and nutritionally adequate diets. To have predictive capacity the exercise should model the drivers of food security, of which climate is only one, as they evolve over time to deliver food security outcomes. Table 1.1 is a simplified example of such an approach, based upon work by the Global Environmental Change and Food Systems (GECAFS) programme in the Indo-Gangetic Plains (Ericksen 2008b).

However, this is really hard to do across the global tropics at the necessary geographic level – that is, sub national – without household survey data to explain why people are

GLOBAL ENVIRONMENTAL CHANGE (GEC)
Change in type, frequency & magnitude of environmental threats

Capacity to cope with &/ or recover from GEC

FOOD SYSTEM RESILIENCE / VULNERABILITY

Exposure to GEC

SOCIETAL CHANGE
Change in institutions, resource accessibility, economic conditions, etc.
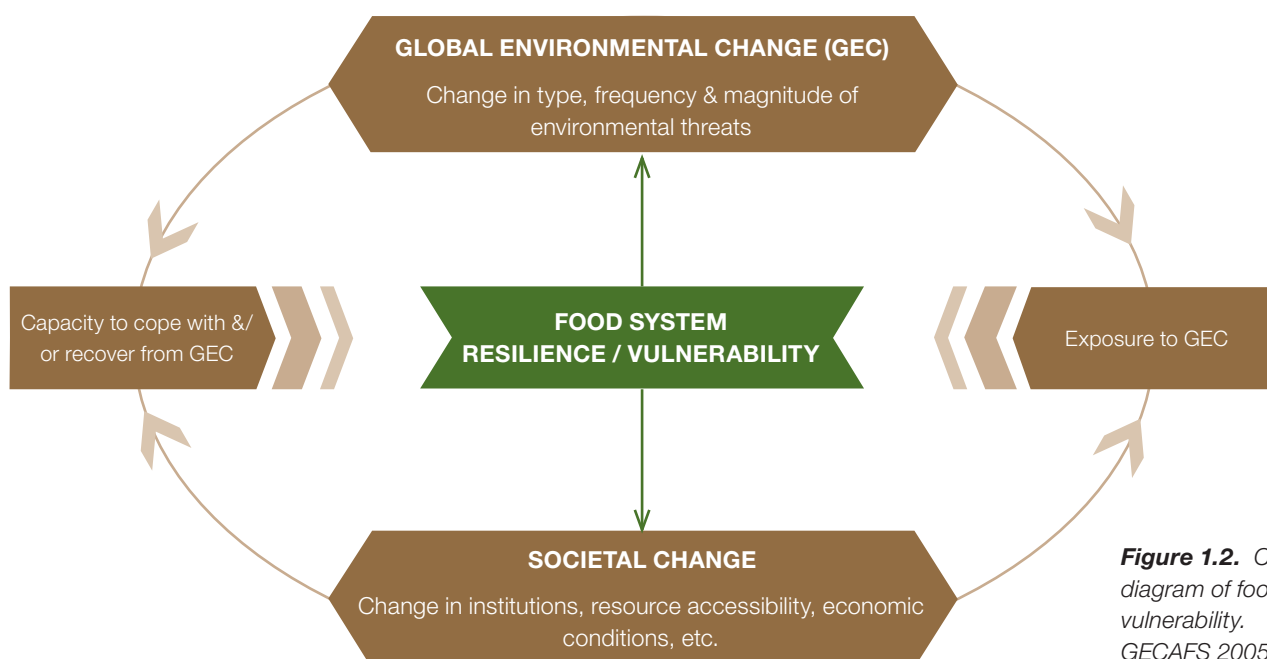
Figure 1.2. Conceptual diagram of food system vulnerability. GECAFS 2005.

Table 1.1. *Vulnerability of determinants of food security to water availability example (Ericksen 2008b)*

Key determinant	Determinant characteristics	Sensitivity to water availability	Adaptive capacity	Vulnerability to water availability
NUTRITIONAL VALUE Food diversity	A diet of rice and lentils supplemented by milk	Cows need four months of rain to produce milk	No functioning milk market to buy from when own production fails	**High**, due to no ability to purchase milk
Primary protein	Lentils are eaten every day	Lentils need two months of rain	Lentil market functions so can always buy them	**Low**, because can purchase lentils
AFFORDABILITY Household incomes	Agriculture is the main source of income	Agricultural earnings depend upon good yields and functioning markets	When crops fail, some work can be found in towns or further away	**Moderate**, due to social and economic constraints on migration

food insecure; for example, how they meet their food basket requirements, and which entitlements fail as the result of a (climate) shock. Devereux (2007) uses data for Malawi to explore how droughts and floods affect each of four food security entitlements: production-based, labour-based, trade-based and transfer-based. With good household data for Malawi, Devereux can evaluate the impact of each type of entitlement failure. He illustrates that production-based entitlements are affected by harvest failure in the short term if households are highly dependent upon agriculture for food, and in the longer term through increased risk, which has been shown to dampen investment in increasing agricultural productivity. In the good year of 2000/2001, only one in four Malawian farmers was self-sufficient in maize, and in the crisis year of 2001/2002 only 2.6% of surveyed households were self-sufficient, while 92% had run out of their own farmed maize after nine months. The impact of these transitory climate shocks on production-based entitlements is compounded by other processes such as decreasing land holdings and a decline in access to inputs. Labour-based entitlements are affected if off -farm employment opportunities to earn cash to purchase food are influenced by a drought or flood. As so few Malawians are self-sufficient in maize, many turn to rural off-farm labour for both cash and food, but these opportunities are declining. In 2001/2002 the number of people seeking off-farm work during the crisis was much higher than the number of available jobs, so relative to the crisis of 1991/1992 labour-based entitlements were much harder to satisfy. Failures of trade-based entitlements occur when weather shock causes food prices to rise, while at the same time asset prices (such as for livestock) fall in market value. In Malawi, there are predictable increases in food prices every year during the hungry season, and in the 2001/2002 crisis retail prices of maize and cassava increased 300% in January 2002. As agricultural markets in Malawi often fail, these high food prices do not attract traders to

supply more food. Finally, transfer-based entitlement can fail if informal social mechanisms are overwhelmed in a prolonged food crisis, as well as due to long-term trends. Several factors combined in rural Malawi, among them social change, the high prevalence of HIV/AIDS, and a low level of urbanization. These combined factors mean there is relatively less remittance income coming from urban areas in times of crisis.

In this project we mapped:

- current food insecurity outcome indicators;

- climate change hotspots in 2050;

- the overlap between these.

2. Climate change hotspot indicators across the global tropics

In this project, we used modelled predictions of changes in temperature and precipitation up to 2050 to derive indicators that are relevant for food systems and food security. The data are available on www.futureclim.info and described in Jones et al (2009). For this report, we used the mean climatology of the four general climate models (GCMs) available from futureclim.info to generate daily weather data and define thresholds important for agriculture and food security. Of the 22 or so climate models used for the IPCC's Fourth Assessment Report (2007), output data are not always readily available for the core variables that are needed to drive many crop and pasture models: precipitation, maximum daily air temperature, and minimum daily air temperature. From the World Climate Research Program's (WCRP) Coupled Model Intercomparison Project phase 3 (CMIP3) multi-model dataset, we obtained data for three GCMs: the CNRM-CM3 model from France, CSIRO-Mk3.0 from Australia, and MIROC 3.2 (medium resolution) from Japan. We also obtained data for the ECHam5 model (from Germany) from the Climate and Environmental Data Retrieval and Archive database at the German Climate Computing Centre. These and other climate models are extensively described in Randall et al (2007).

The maps below are for the entire global tropics and illustrate differences among regions and within continents. In Section 3 we show maps by regions, to better illustrate variability within regions and countries.

The agricultural land area for regions of interest to CCAFS (between 35°S and 45°N, masking out Europe, the US, Argentina, Chile, Australia and New Zealand) are shown in Map 2.1. For our purposes, agricultural land area was defined as places in which the length of growing period (LGP) is greater than or equal to 60 days (i.e. agriculture is possible), plus areas identified as pasturelands and croplands from satellite imagery (see Ramankutty et al 2008). The different categories, including overlap, are mapped below.
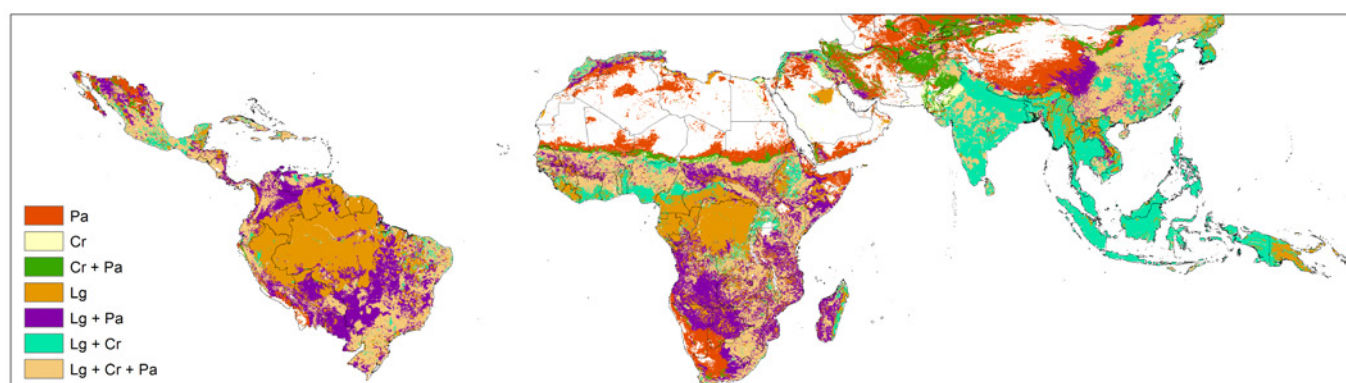
Map 2.1. *The agricultural land area for regions of interest to CCAFS. Pa = pasture, Cr = cropping, Lg = length of growing period is greater than or equal to 60 days.*

Threshold maps

We then defined nine types of climate change hotspots using thresholds for 2050. We used thresholds rather than continuous variables to define discrete areas. The climate change hotspot indicators across the global tropics described and mapped here were derived from the mean outputs of four climate models. There are many uncertainties associated with these indicators, not least the fact that different climate models give different results. These differences may be quite large, particularly for projected changes in rainfall patterns and amounts. The essential reason for this is that there are still many unknowns about the details of how climate may change in the future due to anthropogenic forcings. The climate models are still rather imperfect representations of reality, and as different teams of scientists build these models, these imperfect representations can differ substantially. In Appendix 2, we present probability maps of the eight thresholds derived from GCMs (thus coefficient of variability [CV] rainfall is not included).

1. Areas that will experience more than a 5% reduction in LGP (Map 2.2). LGP is defined by the average number of growing days per year, in which a growing day is one in which the average air temperature is greater than 6°C and the ratio of actual to potential evapo-transpiration exceeds 0.35 (Jones and Thornton 2008). The growing season begins once five consecutive growing days have occurred and ends once 12 consecutive non-growing days occur.
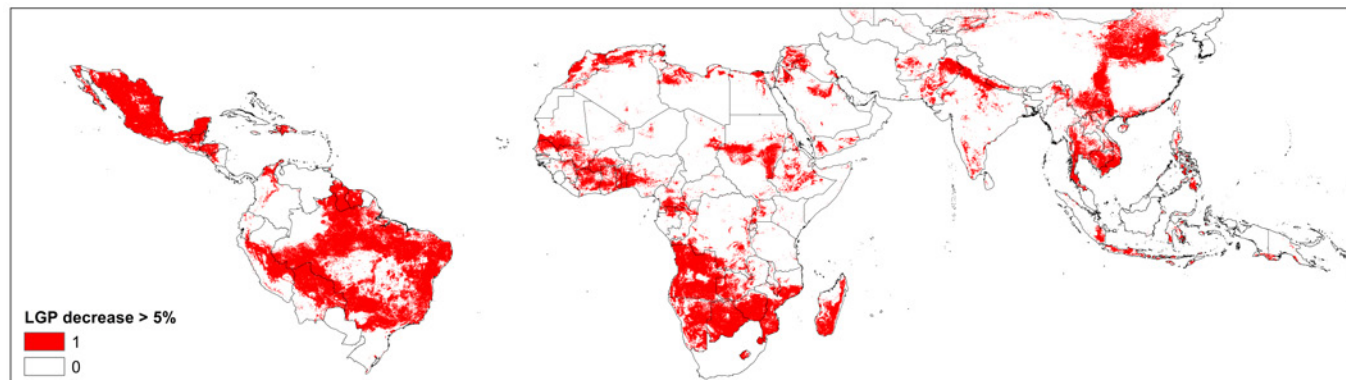
Map 2.2. *Areas that will experience more than a 5% reduction in LGP.*

2. Areas that will flip from LGP greater than 120 days in the 2000s to LGP less than 120 days by 2050 (Map 2.3). Cropping is very difficult in places with an LGP less than 120 days. For example maize is considered marginal in areas with LGP between 121 and 150 (Nachtergaele et al 2002 in Jones and Thornton 2008). Grazing area can also be lost as LGP decreases. Mexico, northeast Brazil, a strip across the African Sahel, Morocco, areas of Southern Africa, and parts of India are highlighted as hotspots with this threshold.
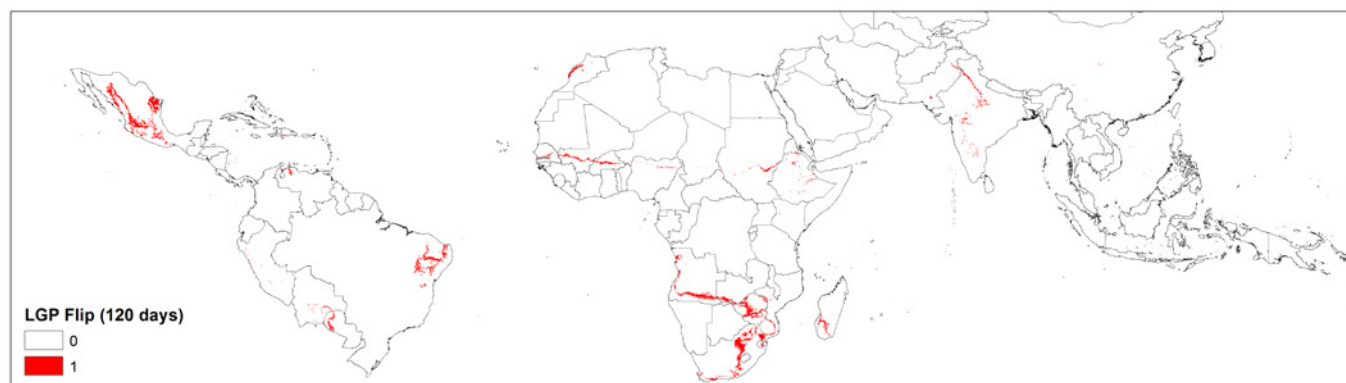
Map 2.3. *Areas that will flip from LGP > 120 days in the 2000s to LGP < 120 days by 2050.*

3. Areas that flip from more than 90 reliable crop growing days (RCGD) per year in the 2000s to less than 90 RCGD by 2050 (Map 2.4). RCGD estimates the total number of reliable growing days over multiple seasons, for those regions with multiple cropping seasons. It also incorporates the changing probability of crop failure. Ninety RCGD is the equivalent of 120 days LGP, so when RCGD drops below 90 days cropping becomes very difficult. RCGD is a more discriminating indicator than LGP for rain fed agricultural crops. The area highlighted expands with this threshold, to include a range of areas across the global tropics in south Asia, Southern Africa, northeast Brazil, west Mexico, East and West Africa and east Asia.
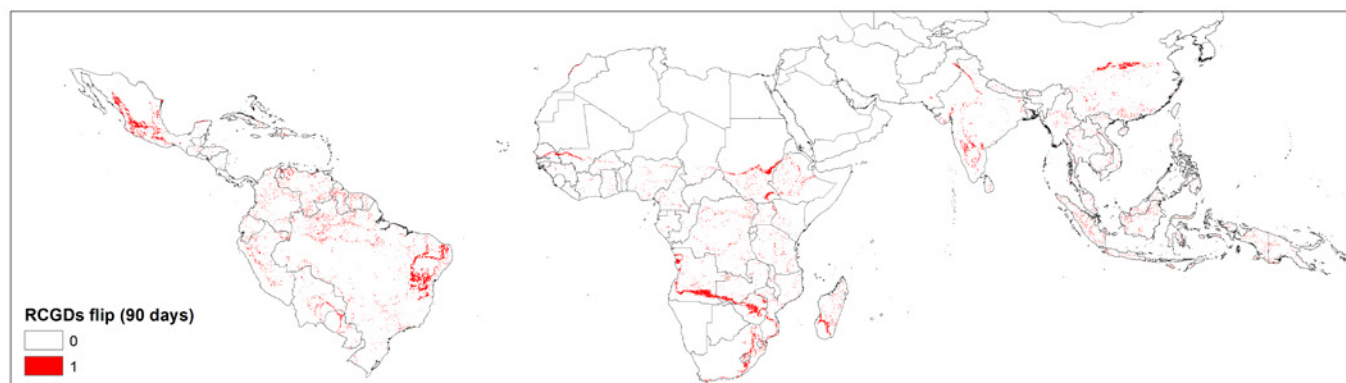
Map 2.4. *Areas that flip from > 90 reliable crop growing days (RCGD) per year in the 2000s to < 90 RCGD by 2050.*

4. Areas where the average annual temperature flips from less than 8°C in the 2000s to more than 8°C by 2050 (Map 2.5). This could expand the crop suitability of these areas. The Andes, parts of central and highland south Asia and south China are highlighted.

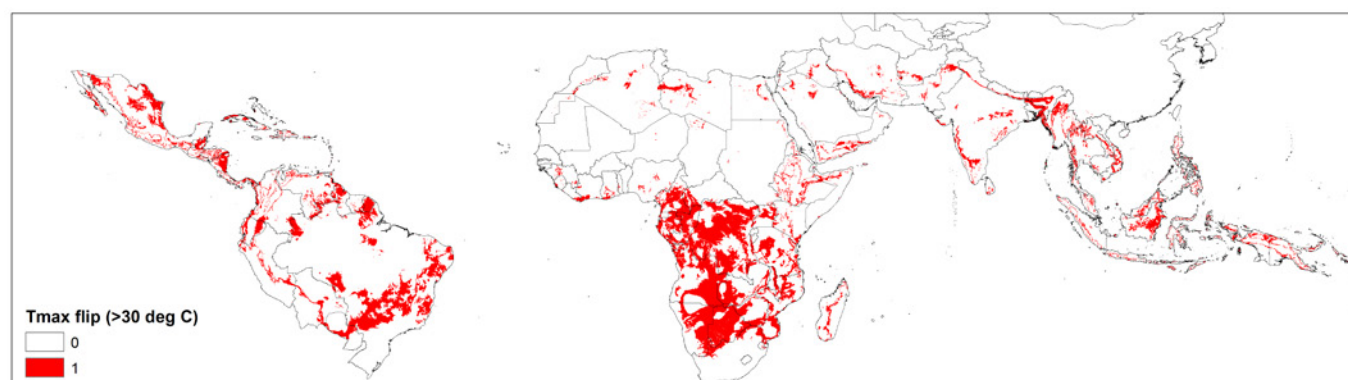**Map 2.5.** *Areas where the average annual temperature flips from < 8°C in the 2000s to > 8°C by 2050.*

5. Areas where average annual maximum temperature will flip from under 30°C to over 30°C (Map 2.6). While this is the maximum temperature that beans can tolerate, rice and maize yields suffer at higher temperatures than this, as do other staple crop yields. Grazing vegetation will also suffer at such high temperatures and we could see switches in species with implications for palatability for livestock. Higher temperatures also affect food safety, for example milk storage, and disease transmission patterns, such as malaria. Significant areas of Latin America, Africa and Southeast Asia are highlighted.

Map 2.6. *Areas where average annual maximum temperature will flip from < 30°C to > 30°C .*

6. Areas where the maximum temperature during the primary growing season is currently less than 30°C but will flip to more than 30°C by 2050, during the primary growing season (defined as the longest for a given area) (Map 2.7). This shrinks the highlighted area somewhat, but these areas are more vulnerable to the increased riskiness of cropping because it is specific to the primary growing season for a given area.
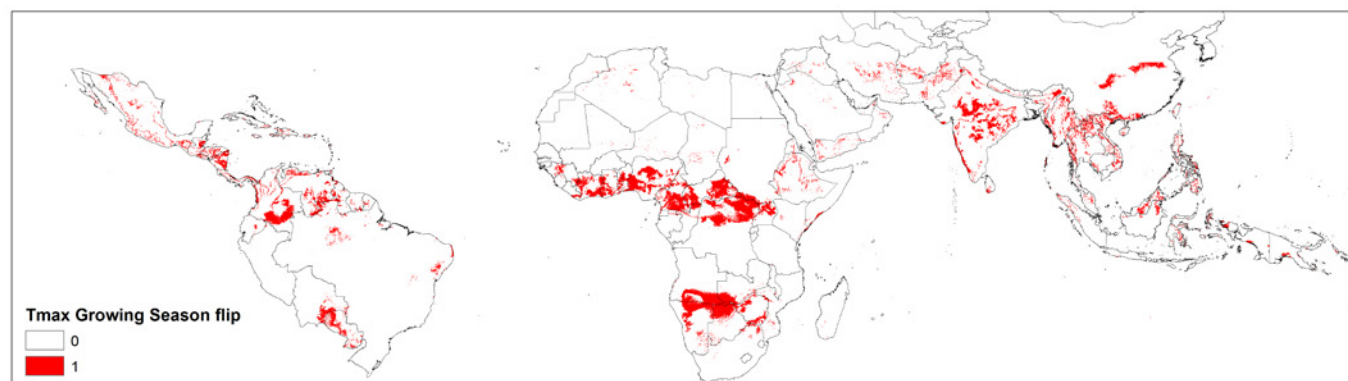
Map 2.7. *Areas where maximum temperature during the primary growing season is currently < 30°C but will flip to > 30°C by 2050 (during the primary growing season).*

The next three thresholds attempt to characterize how climate change may affect variability. Many believe that climate change will increase variability (Easterling et al 2007 p 283), although at the moment climate modellers cannot predict this with any accuracy.

7. We first show where coefficient of variability of rainfall is currently high (Map 2.8), as increases would make cropping even riskier in such areas. In most heavily cropped areas (see Map 2.1) CV of rainfall is less than 25%, with the exception of India. There is very little cropping in areas with CV of rainfall greater than 45%. But large areas of Africa, south Asia, Mexico, and the Middle East have CV greater than 25%.
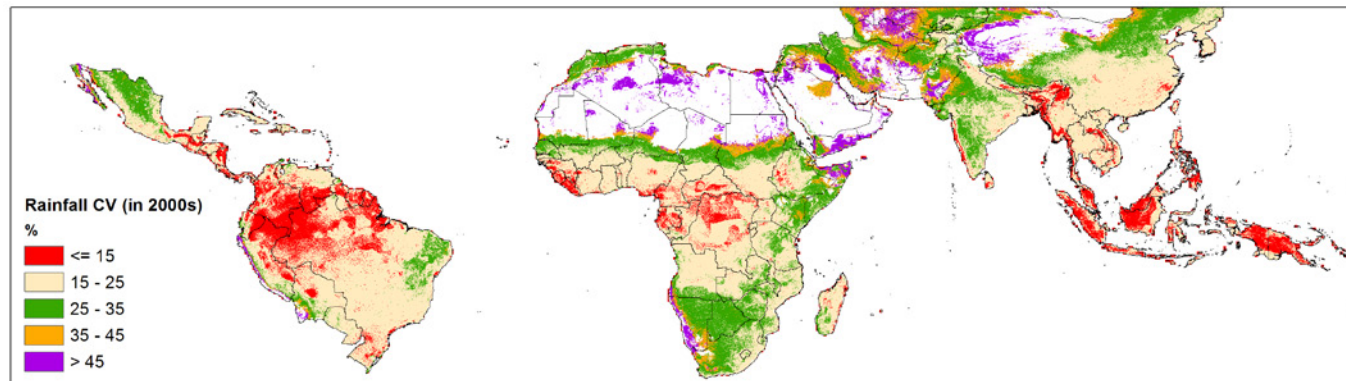
Map 2.8. *Areas where CV of rainfall is currently high.*

An analysis of percent area cropped and CV of rainfall shows that the majority of cropped areas fall within a CV range of 12% to 37%, with the mode occurring at 21%. We can use this to divide areas of the tropics as shown in Map 2.9, below. Those croplands with rainfall CV less than 21% are white and rainfall CV more than 21% are red. Large areas of the tropics are already in the over 21% zone, including heavily cropped areas such as south Asia, Mexico, Southern Africa, and northern Nigeria.
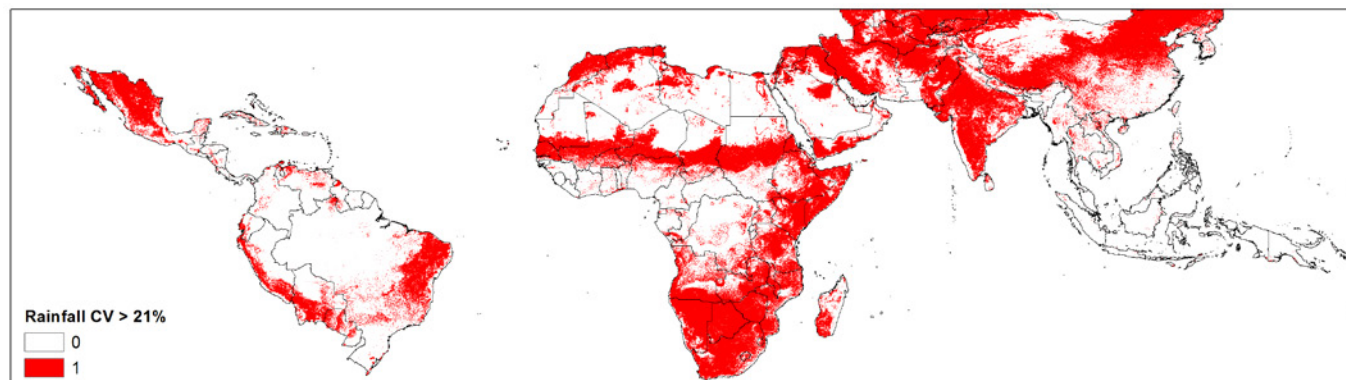
Map 2.9. *Areas where CV of rainfall is more than 21%.*

8. Changes in variability could mean less rain per rainfall event. Map 2.10 shows areas where rainfall per day decreases by 10% or more between 2000 and 2050. In areas that are already arid or semi-arid this poses a significant problem for cropping or livestock grazing.
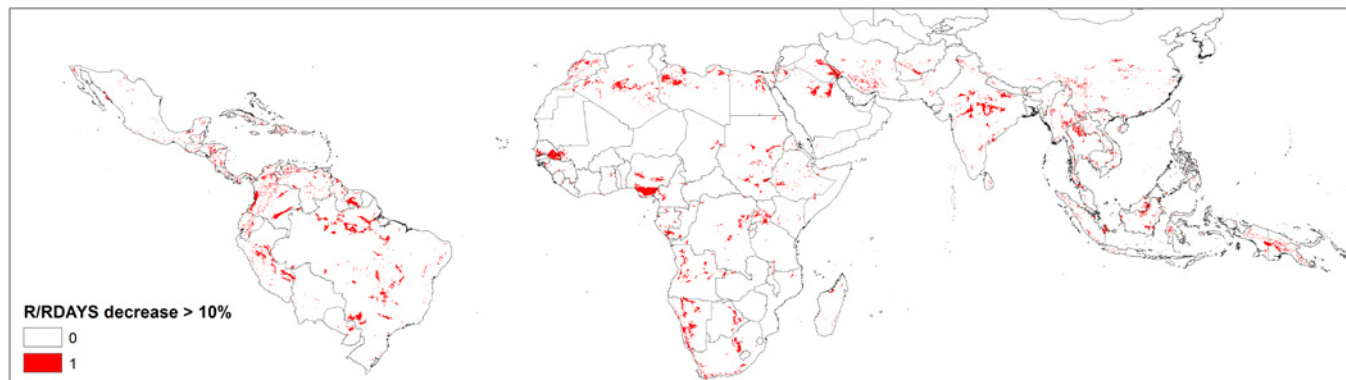
Map 2.10. *Areas where rainfall per day decreases by 10% or more between 2000 and 2050.*

9. Conversely, in Map 2.11 below, we identify where the amount of rainfall per rainy day increases by 10% between 2000 and 2050. This is a proxy for increased rainfall intensity, which can cause soil erosion and greater runoff and therefore limit the effectiveness of rainfall or increase flooding.

Map 2.11. *Areas where rainfall per rainy day increases by 10% between 2000 and 2050.*

In a last step of the climate threat analysis, we classified areas by the number of climate change thresholds identified (excluding LGP decrease by more than 5%). For each pixel, the number of potential climate threats was calculated. In case the pixel is exposed to a positive temperature flip (from less than 8°C to more than 8°C), we lowered the number of threats by one (Map 2.12).
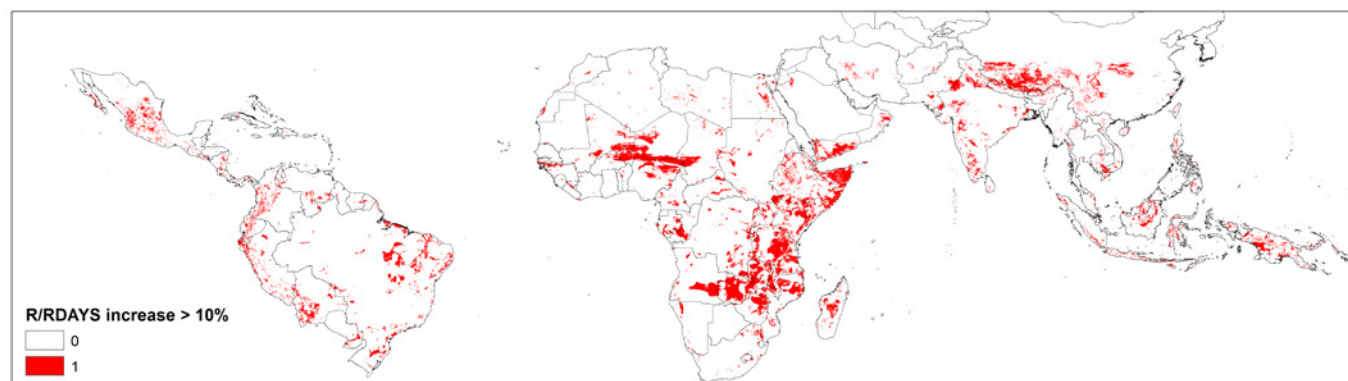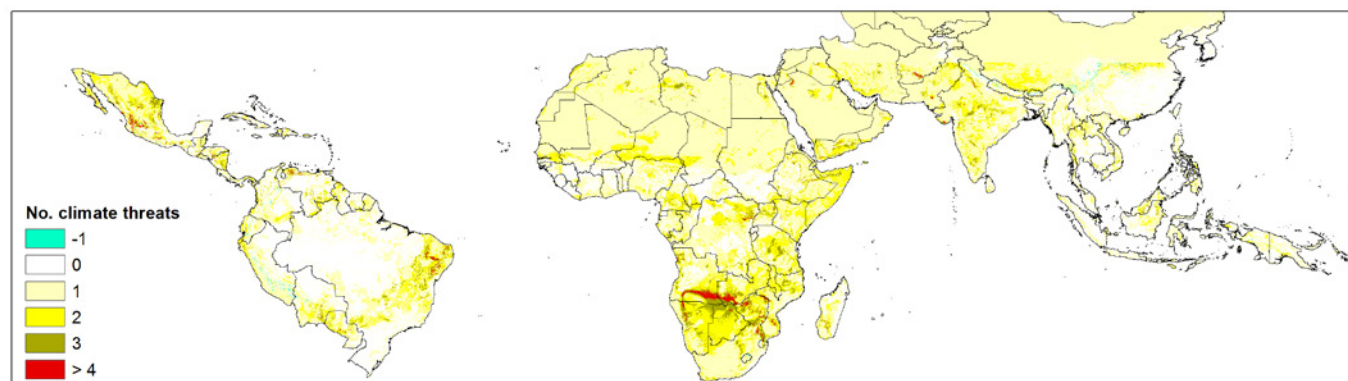

Map 2.12. *Number of identified climate change thresholds.*

Southern Africa has the largest area (across Namibia, Angola, Zambia, Botswana, Mozambique and South Africa) with multiple threats, followed by northeastern Brazil, Mexico, Guyana, Nicaragua, and small areas in Tanzania, Ethiopia, the DRC, Uganda, India, and Pakistan, as well as the Middle East.

We calculated domains for each individual threshold, rather than this combined one, as each threshold represents a different climate change impact, and hence the vulnerability domain size and implications differed. For a targeting exercise, exploring these differences is useful.

Risk Maps

The UNEP GRID project has compiled maps of global disaster risk (UNEP 2011). We show the maps for drought and flood here.

Drought

The risk of drought is an important factor in considering the potential for food insecurity because droughts reduce food availability through their impact on local production. Map 2.13 below shows the frequency SPI (standardized precipitation risk), which i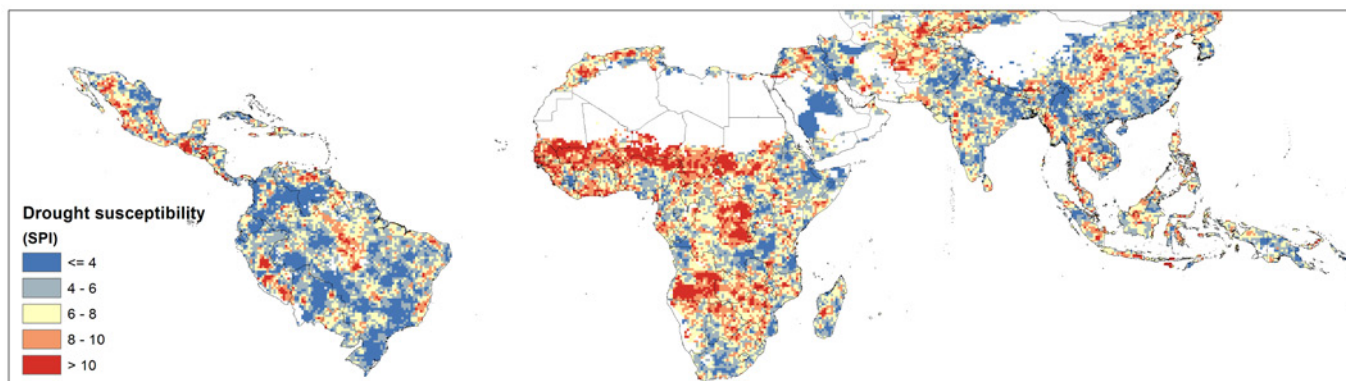s defined as the average number of drought events per year per pixel (for the period 1974-2004), where drought events are identified as three consecutive months with less than 50% of precipitation as compared with average.

Map 2.13. *The frequency SPI defined as the average number of drought events per year per pixel (for the period 1974-2004).*

Flood

The risk of flood is also important when considering the potential for food insecurity because floods destroy crops and reduce food availability. Map 2.14 below shows average flood frequency based upon data from the Dartmouth Flood Observatory. The Global Flood Hazard Frequency and Distribution is a 2.5 by 2.5 minute grid derived from a global listing of extreme flood events between 1985 and 2003 (poor or missing data in the early to mid 1990s), compiled by Dartmouth Flood Observatory and georeferenced to the nearest degree. The resultant flood frequency grid was then classified into 10 classes of approximately equal number of grid cells. The greater the grid cell value in the final data set, the higher the relative frequency of flood occurrence. The dataset is a result of the collaboration between the Center for Hazards and Risk Research, and the Columbia University Center for International Earth Science Information Network. South and Southeast Asia are highlighted in particular.

Map 2.14. *Average flood frequency based upon data from the Dartmouth Flood Observatory.*

In section four of the report, these maps are compared with future drought and intense rainfall likelihoods.

We did not map areas at risk of sea level rise, but Nicholls et al (2007) suggest that certain coastal environments are at risk: deltas, coral reefs, low-lying coastal wetlands, small islands, and soft areas of coastline. They identify south and Southeast Asian deltas and the Nile delta as particularly vulnerable because of high population densities.

# 3. Food security maps across the global tropics

An expanded data set was collected and is shown in Appendix 1. For the mapping exercise, we were limited by the indicators available for the countries of interest - most are national level data. The indicators are described and mapped by the food security component each one represents. We endeavoured to map at least two indicators per food security component. Note that these are indicators of food security outcomes rather than drivers of food (in)security. In this section maps for the entire global tropics are shown. Regional maps are in Section 5.

Availability indicators

Current crop yields

Current crop yields are mapped using data from the International Food Policy Research Institute (You et al 2000). These figures represent food availability, the first pillar of food security. Yields are mapped by pixel across the global tropics for maize, rice, millet, sorghum, beans, cassava and wheat for the years 1999-2001.

Map 3.1 illustrates the low maize yields across much of Africa (except parts of Southern Africa and Cameroon), south Asia, and much of Southeast Asia. Yields are higher in China, south India and much of Latin America. Note that this does not tell us about preferences for maize, which are, for example, high in Kenya, Tanzania and across Southern Africa.
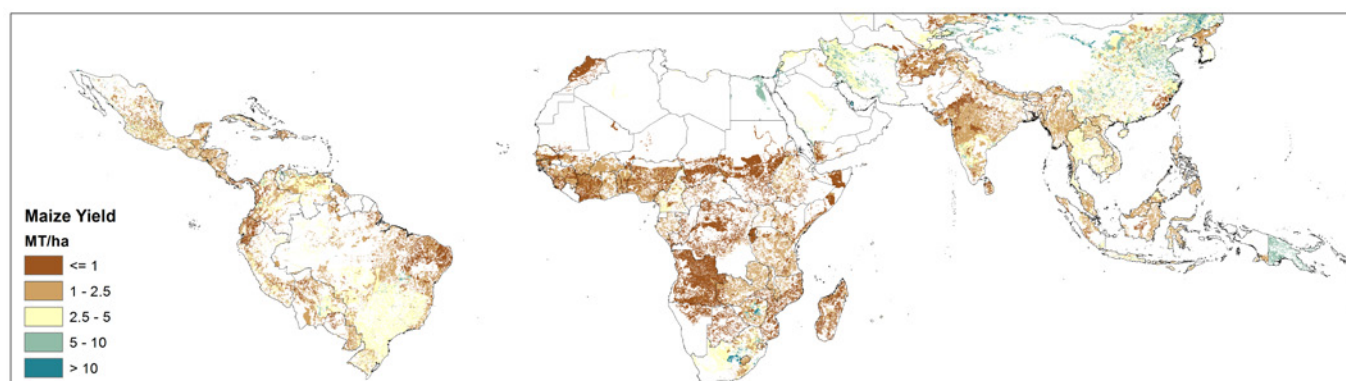
Map 3.1. *Maize yields mapped by pixel across the global tropics.*

Again, yields are low for rice across most of Africa and central India (Map 3.2). Yields are variable across Southeast Asia and Latin America but higher generally than in Africa.
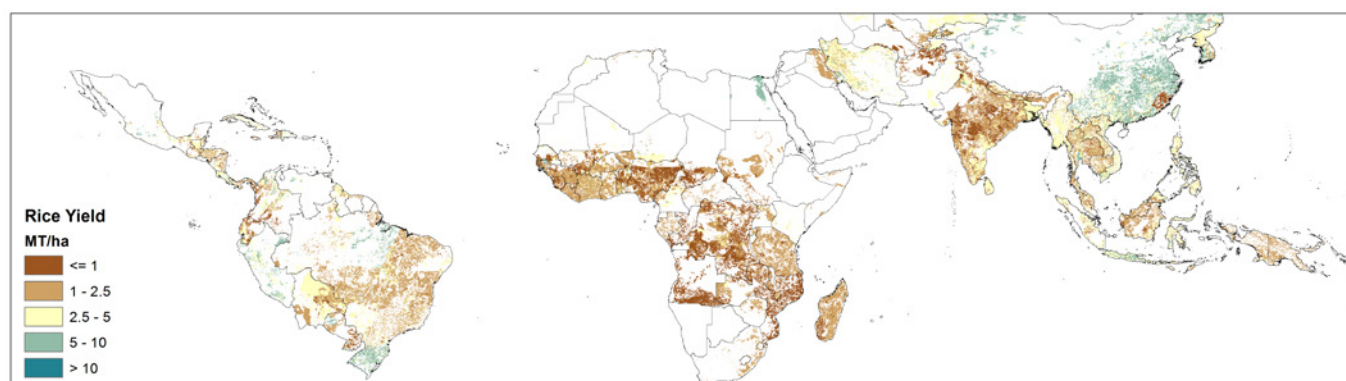
Map 3.2. *Rice yields mapped by pixel across the global tropics.*

Map 3.3 shows the low millet yields across all of the tropics, except parts of China. Note that millet is not grown in Latin America.

Map 3.3. *Millet yields mapped by pixel across the global tropics.*

Map 3.4 shows that beans are extensively grown across south and Southeast Asia, as well as much of Latin America. They are hardly grown in West and Central Africa. Yields only exceed 2.5 t ha in east China and parts of North Africa.
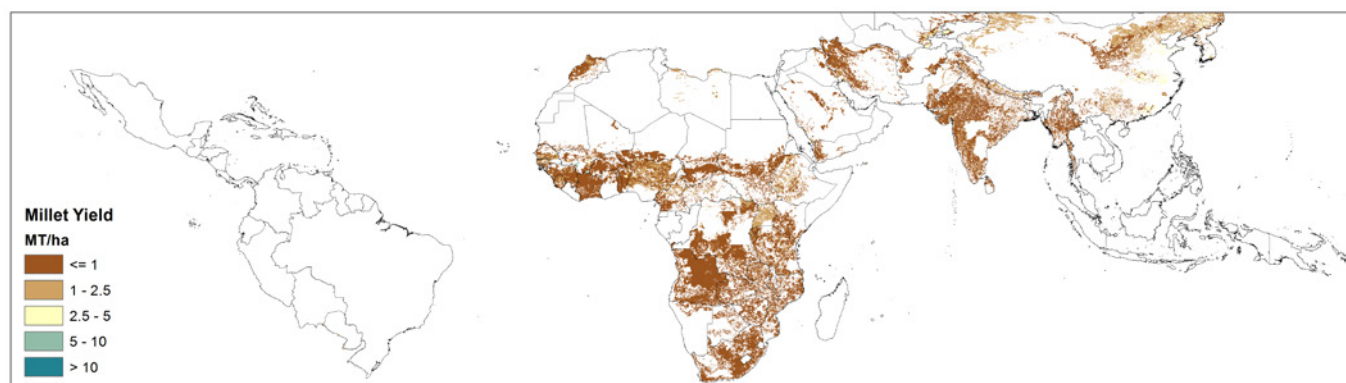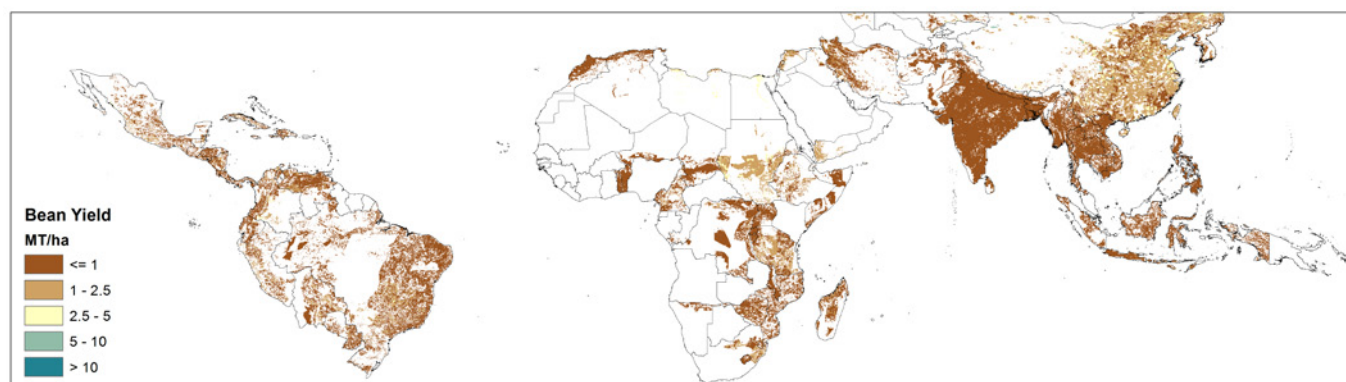

Map 3.4. *Bean yields mapped by pixel across the global tropics.*

Wheat (Map 3.5) is hardly grown in Africa or Brazil, except in the highland areas. It is extensively grown across central and south Asia, as well as China. Yields range from less than 1 t ha to 5-10, with notable spots of high productivity in India, China, Egypt, Zimbabwe and Mexico.
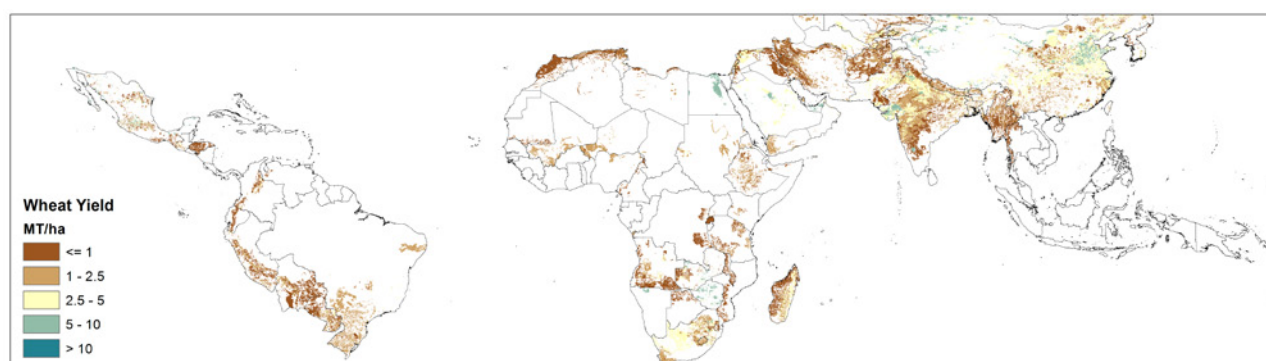
Map 3.5. *Wheat yields mapped by pixel across the global tropics.*

The next crop mapped (Map 3.6) is sorghum. In addition to the regional differences where it is grown, the yield differences are notable. Yields are higher in China and Latin America than in Africa or India.
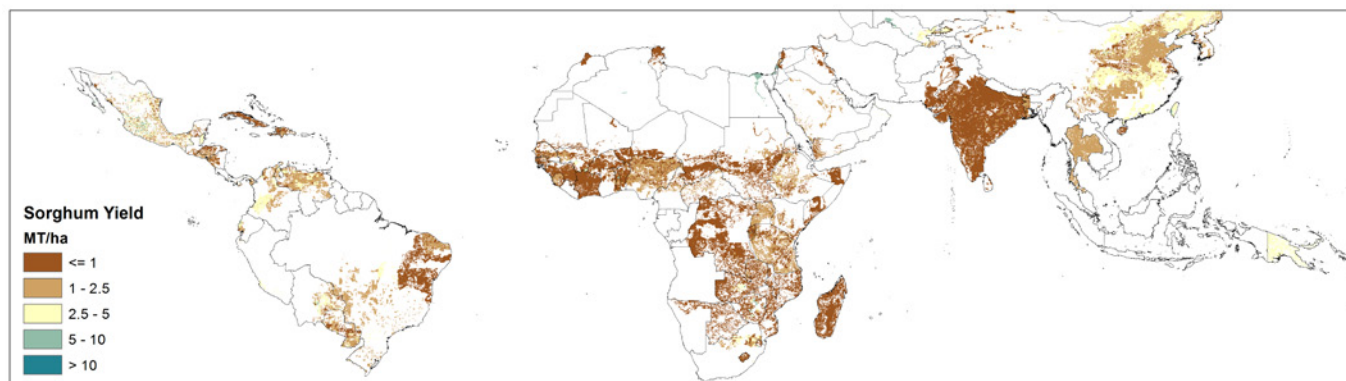
Map 3.6. *Sorghum yields are mapped by pixel across the global tropics.*

The last crop mapped is cassava (Map 3.7), which is extensively grown in Latin America and Southeast Asia, as well as some parts of Africa. It is an important food security crop as it grows in marginal conditions.
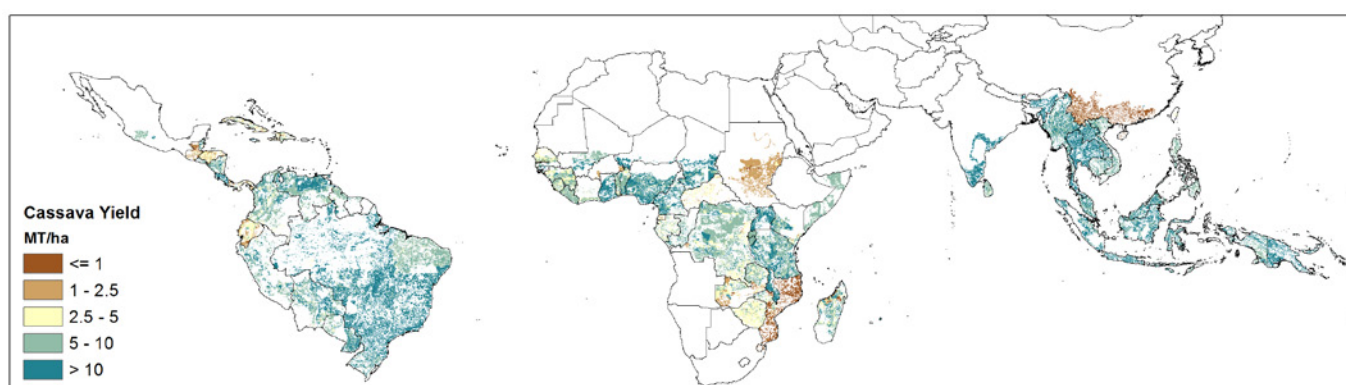
Map 3.7. *Cassava yields mapped by pixel across the global tropics.*

Net food production index number per capita

The per capita net food production index number (PIN) is a national level indicator with data obtained from the FAO statistics division, FAOSTAT. A country's per capita PIN illustrates the relative level of the aggregate volume of food production per capita for each year in comparison with the base period 1999–2001. The category of food production includes commodities that are considered edible and that contain nutrients. As such, coffee and tea, although edible, are excluded, along with inedible commodities, because they have little to no nutritive value. This indicator is included to demonstrate the pillar of availability of food from national production, as it monitors trends in production per capita. If the index is above 100, production is increasing relative to the base year. The average for 2003–2007 is shown below.

Map 3.8 shows interesting differences by country, as well as by region. Africa has the most countries with PIN less than or equal to 105. In Latin America, Panama, Colombia, Venezuela, Suriname and Guyana have stagnant PIN, while Mexico, Brazil, Bolivia and the rest of Central America (except El Salvador and Belize) have PIN above 100. Much of Central and Southern Africa has PIN below 105, while several countries in East and West Africa are above 105. China and Southeast Asia are also above 105 for the most part, while the countries of the Indo-Gangetic plains are around 100. Very few countries have high growth (over 125).
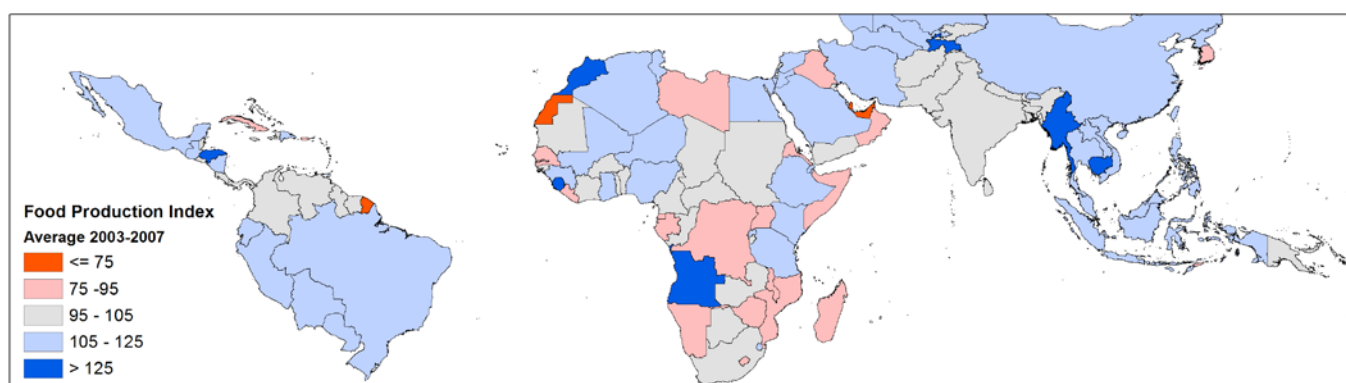
Map 3.8. *Average food production index 2003-2007.*

Access indicators

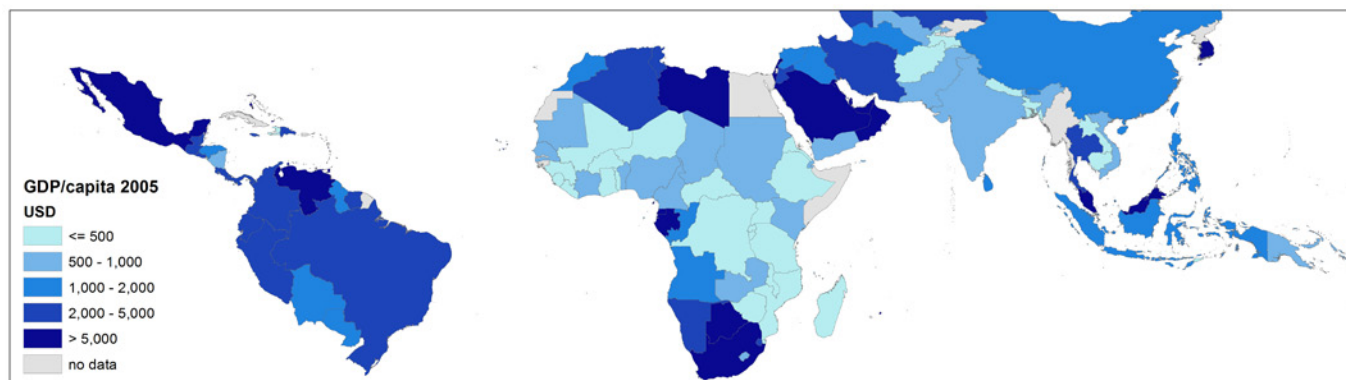**GDP per capita (current USD)**

GDP per capita is the gross domestic product of a country divided by its midyear population. Data are shown for 2005 and come from World Bank national accounts data and OECD national accounts data files. The information was downloaded from the World Development Indicators database of the World Bank databank, World Development Indicators, (http://databank.worldbank.org). This is a national level indicator that reflects the ability of consumers to purchase food, as it is a proxy for available income per capita.

GDP per capita is also variable across countries and regions (Map 3.9). In Latin America, Mexico and Venezuela have GDP per capita over USD 5000, while Nicaragua is between USD 500 and 1000. In Africa, there are a number of countries with GDP below USD 500; South Africa, Guinea Bissau, Namibia, Gabon, Angola, Tunisia, Morocco, Libya, Botswana and Algeria have GDP higher than USD 1000. In south Asia, India and Pakistan have GDP of USD 500–1000, contrasting with Nepal and Bangladesh. In Southeast Asia, Vietnam, Cambodia, Laos and Papua New Guinea are all below 1000.


Map 3.9. *GDP per capita 2005.*

Current poverty levels: % population living below USD 2 a day

Percent of population living with less than USD 2 per day is a poverty indicator mapped by the CGIAR CSI (Wood et al 2010). Current poverty levels are an indicator of food insecurity because they point to the income people have to spend on food and hence their vulnerability to an increase in the price of food. It is well known that the poorer a household is the greater the percent of income spent on food. This is another indicator of economic access to food (affordability).

As these data are available at the sub-national level (for those countries reporting), more heterogeneity can be analyzed (see the regional maps in Section 5). In Map 3.10 note that a country such as South Africa, which has a high GDP, also has many people living below the poverty line. Regionally, sub-Saharan Africa, south and Southeast Asia and much of west China stand out for having more than 60% of the population living on less than USD 2 per day. Within Latin America, Nicaragua, Brazil, Bolivia and Venezuela have significant portions of the country with greater than 40% below the USD 2 per day threshold. In Africa, Sudan and Tunisia stand out for their wealth; note that these data mask within-country differences. In Southeast Asia, Thailand and Malaysia are wealthier.
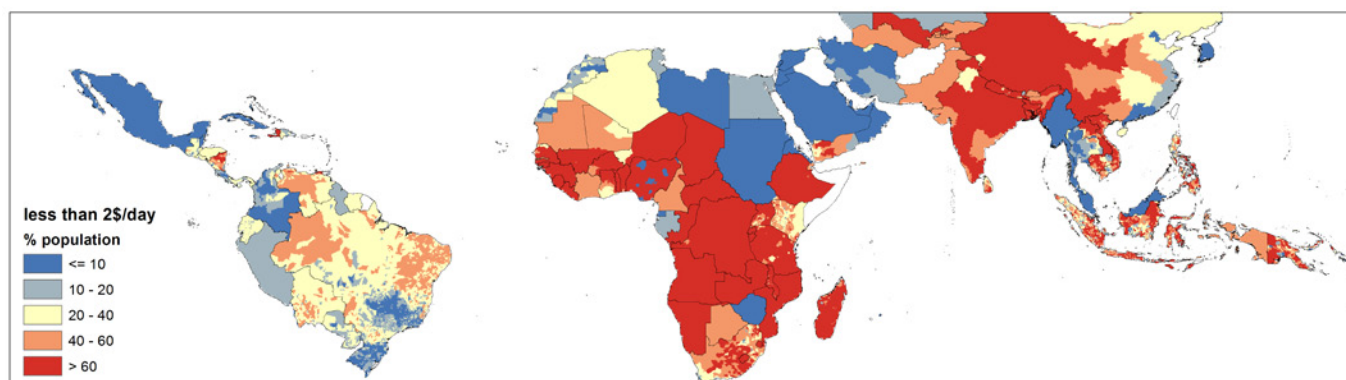
Map 3.10. *Population living on less than USD 2 per day.*

Transport time to markets

The time that food takes to reach markets affects households' ability to buy it (Nelson 2008). In Map 3.11 below, within-region differences are most noticeable; for example East Africa (especially Ethiopia and Southern Sudan) has fewer urban centres than West Africa, while India stands out for its high level of urbanization. This is one indicator of physical access to food, but it assumes that closer proximity necessarily increases food security, which is not the case. If other issues such as poverty or high HIV incidence affect food security then physical access will not make a difference. The increasing data about urban food insecurity illustrate this point. This is why no single indicator of food security can explain food security status overall.
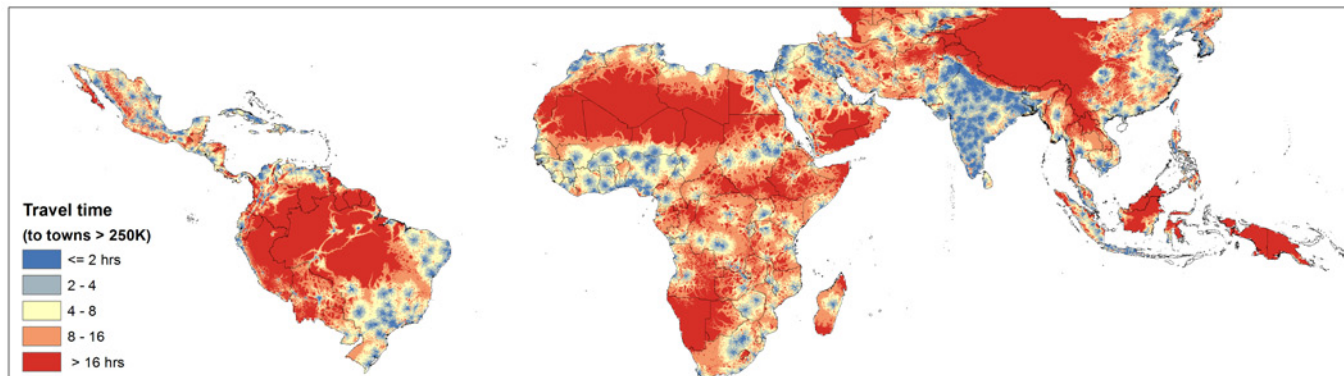
Map 3.11. *Transport time to markets.*

Monthly staple food prices

Monthly prices of staple foods from the capital city of each focus country are graphed to illustrate price variability over time at the sub-national level. Prices have been obtained from FAO's Global Information and Early Warning System (GIEWS) price tool (www. fao.org/giews/pricetool/). The nominal monthly prices were converted to real prices using consumer price indices (CPI) of each country from the World Development Indicators database (http://databank.worldbank.org). Consumer price indices reflect changes in the cost to the average consumer of acquiring a basket of goods and services. It is generally assumed that greater price volatility seasonally or annually affects low income consumers' ability to access sufficient food. As we were only able to get data for the national capitals these data are discussed in the regional reports.

Utilization indicators

Malnutrition prevalence - stunting

Prevalence of child malnutrition is the percentage of children under 5 whose height for age is more than two standard deviations below the median for the international reference population - known as stunting (ages 0-59 months). For children up to two years old height is measured by recumbent length, and for older children height is measured by stature while standing. The data are based on the World Health Organization's new child growth standards released in 2006 and downloaded from the World Development Indicators database. Stunting is a lagging indicator and reveals chronic food insecurity within a population. Food insecurity does not always lead to undernourishment.

In Map 3.12 sub-Saharan Africa, south and Southeast Asia stand out among the regions for having most countries reporting stunting prevalence greater than 40%.
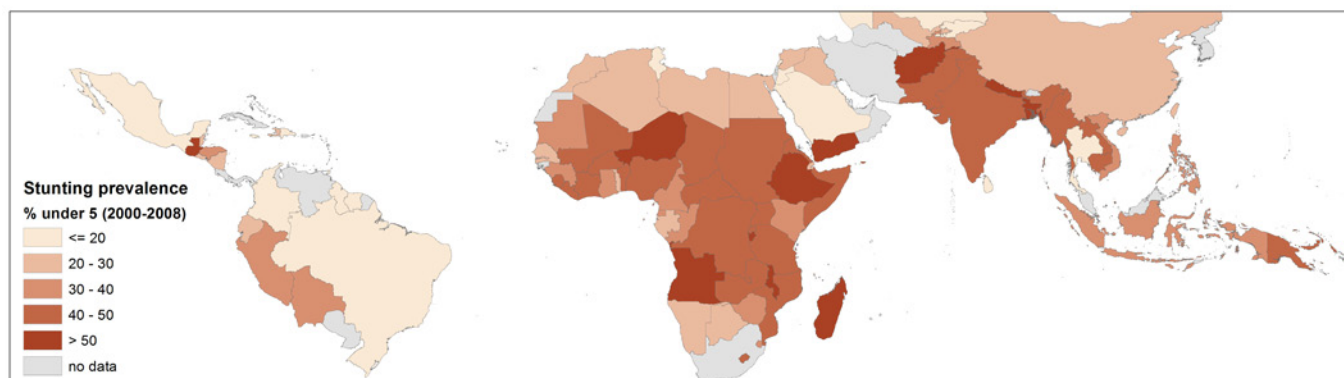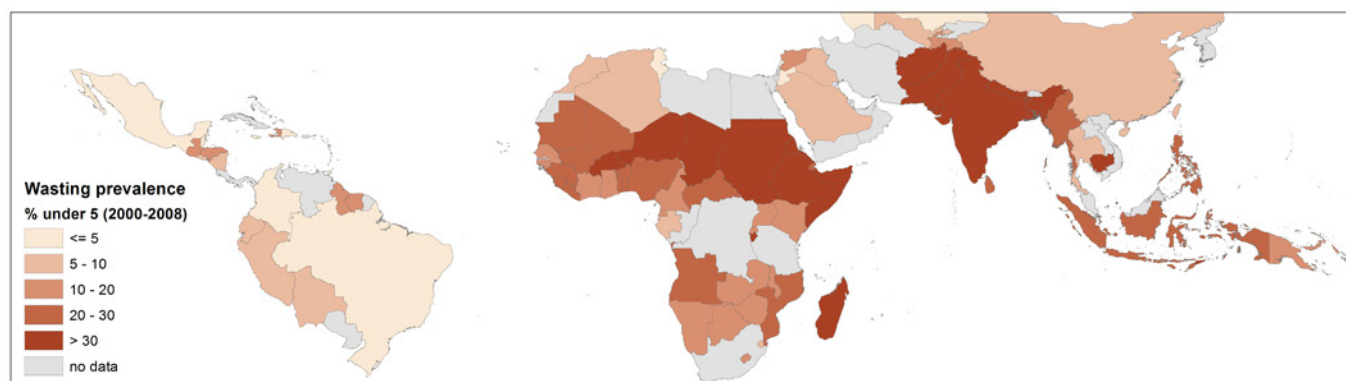

Map 3.12. *Stunting prevalence.*

Malnutrition prevalence - wasting

Prevalence of child malnutrition is the percentage of children under age 5 whose weight for age is more than two standard deviations below the median for the international reference population (ages 0-59 months) – known as wasting (Map 3.13). The data are based on the WHO's new child growth standards released in 2006 and also downloaded from the World Development Indicators database. As with stunting, low weight for age (underweight) indicates chronic food insecurity. The Millennium Development Goal on reducing hunger tracks countries' progress in reducing this prevalence by half (UN 2010).

Wasting is a stricter indicator than stunting because it indicates a more severe level of malnutrition.

Map 3.13. *Wasting prevalence.*

The total number of malnourished children per square kilometre is shown in Map 3.14 below. Malnourished is defined as above for wasting (Herrero et al 2009).

Map 3.14 shows the density of hungry people: most of south Asia, Malawi, Ethiopia, Uganda, parts of Kenya and Tanzania, much of West Africa, and large areas of China, Vietnam, Laos, Indonesia, Guatemala and Nicaragua.
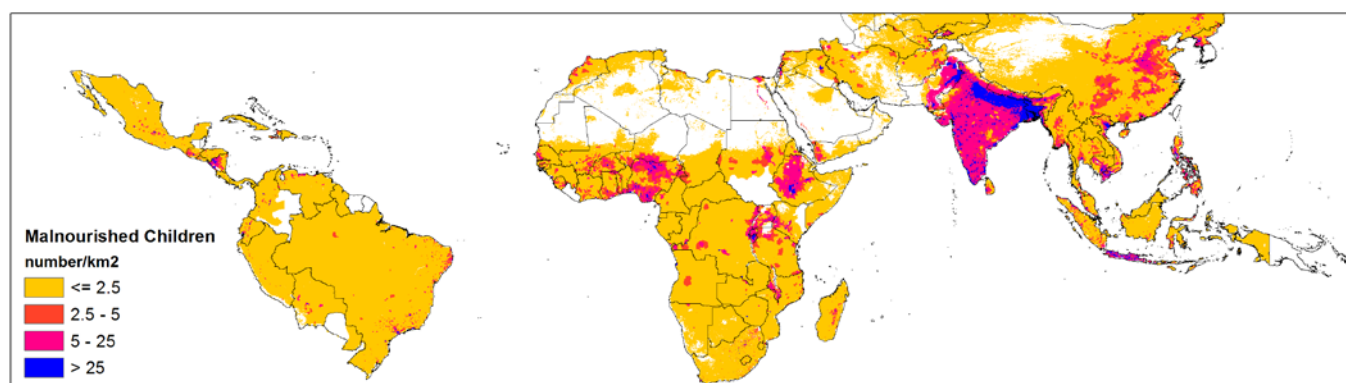
Map 3.14. *Malnourished children per sq km.*

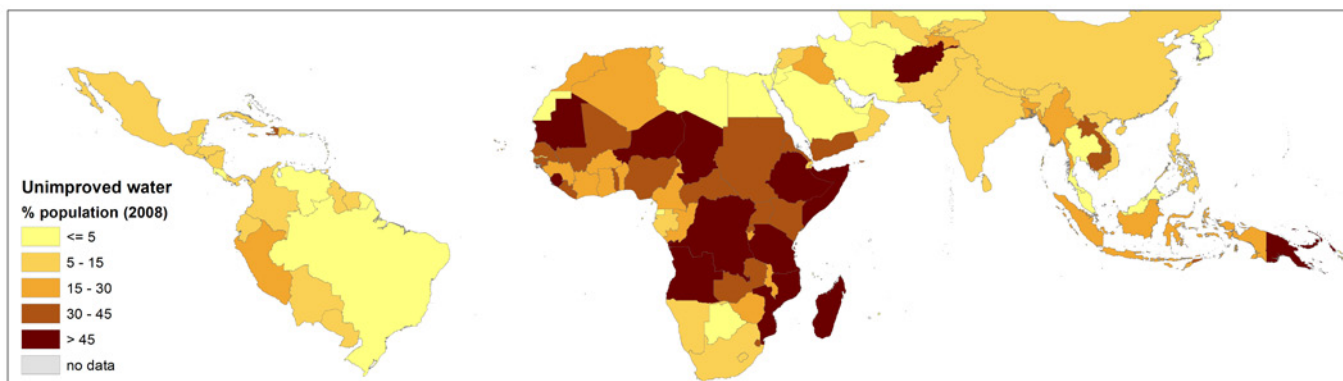**Population using unimproved water source**

The percentage of a country's population using improved water sources can act as an indicator of the utilization aspect of food security, as contaminated water often spreads diseases that affect the body's ability to make use of food consumed. In Map 3.15 much of sub-Saharan Africa stands out for having more than 30% of the population reliant on unimproved water, as does Afghanistan and Papua New Guinea. Data for this indicator were downloaded from the WHO/UNICEF Joint Monitoring Program (JMP) for Water Supply and Sanitation, (www.wssinfo.org/data-estimates/table/).

Unimproved sources of drinking water are defined as:

- Unprotected spring. This is a spring that is subject to runoff, bird droppings, or the entry of animals. Unprotected springs typically do not have a 'spring box'.

- Unprotected dug well. This is a dug well for which one of the following conditions is true: 1) the well is not protected from runoff water; or 2) the well is not protected from bird droppings and animals. If at least one of these conditions is true, the well is unprotected.

- Cart with small tank/drum. This refers to water sold by a provider who transports water into a community. The types of transportation used include donkey carts, motorized vehicles and other means.

- Tanker-truck. The water is trucked into a community and sold from the water truck.

- Surface water is water located above ground and includes rivers, dams, lakes, ponds, streams, canals, and irrigation channels.

- Bottled water is considered to be improved only when the household uses drinking water from an improved source for cooking and personal hygiene; where this information is not available, bottled water is classified on a case-by-case basis. (WHO / UNICEF 2010)


Map 3.15. *Population using unimproved water source.*

Resource pressure

We also mapped two indicators of resource pressure, as a possible indicator of future vulnerability.

Population growth rate
The annual population growth rate is based on the de facto definition of population, which counts all residents regardless of legal status or citizenship, except refugees not permanently settled in the country of asylum, as they are generally considered part of the population of the country of origin. Information was downloaded from the World Development Indicators database. This is an indicator of resource pressure, which can affect future food security if agricultural productivity does not meet population growth and trade in food does not rise to meet food needs. Much of sub-Saharan Africa reports annual growth rates of over 2%, as do Pakistan and Afghanistan, as well as Guatemala, Papua New Guinea and the Gulf states (Map 3.16).
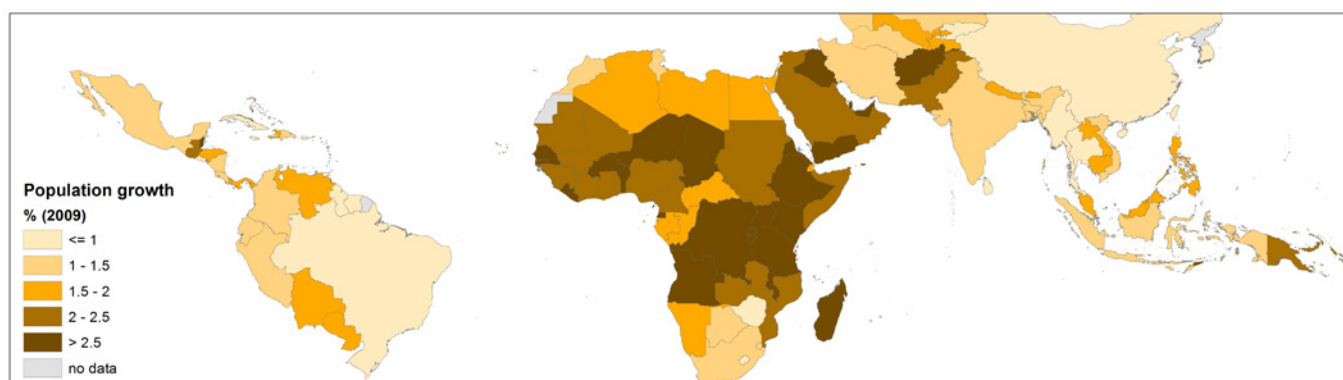
Map 3.16. *Annual population growth.*

Agricultural area per capita

This indicator has been calculated using data from FAOSTAT on agricultural area and national population (FAOSTAT 2011). Agricultural area (expressed in 1000 hectares) is the sum of areas under arable land[2], permanent crops[3] and permanent meadows and pastures[4]. When divided by population, this indicates a country's available resources for producing its own food and long-term trends reflect the amount of resource pressure being exerted by growing populations. South and Southeast Asia have very low arable land per capita; Ethiopia, Uganda, China, Cameroon, the DRC, Benin, Guatemala, Honduras El Salvador and Panama are also less than 0.5 (Map 3.17).
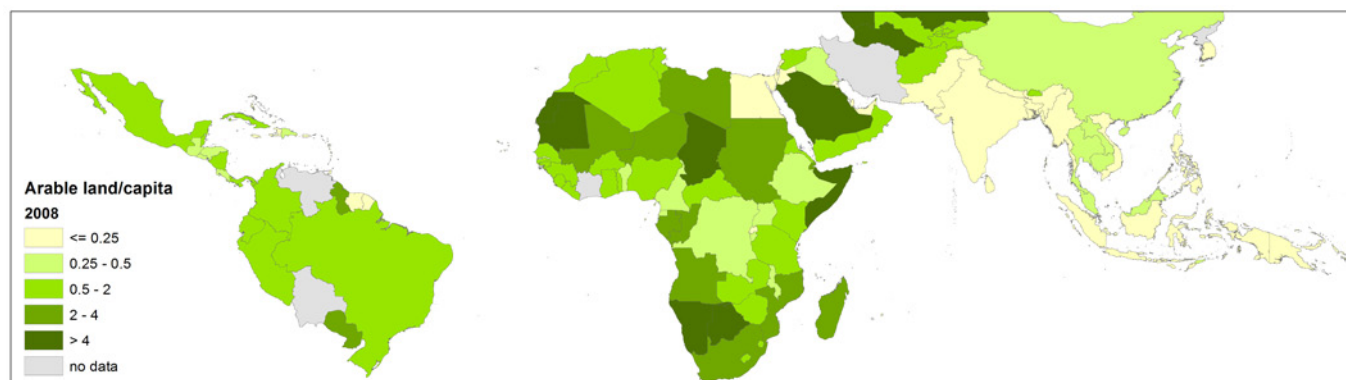
Map 3.17. *Arable land per capita.*

[2] Land under temporary agricultural crops, temporary meadows for mowing or pasture, land under market and kitchen gardens and land temporarily fallow (less than five years). The abandoned land resulting from shifting cultivation is not included in this category. Data for arable land are not meant to indicate the amount of land that is potentially cultivable.

[3] Land cultivated with long-term crops which do not have to be replanted for several years (such as cocoa and coffee); land under trees and shrubs producing flowers, such as roses and jasmine; and nurseries (except those for forest trees, which should be classified under 'forest').

[2] Land used permanently (five years or more) to grow herbaceous forage crops, either cultivated or growing wild (wild prairie or grazing land).

4. Vulnerability domains

In this part of the report, we attempted to overlay the climate change hotspots with the food insecure hotspots. We took a 'domain' approach to vulnerability, overlaying indicators for exposure, sensitivity and coping capacity (using the definition of vulnerability given earlier) and then classifying areas of the tropics (or domains) accordingly. Although we collected data for a number of food security outcomes, for this exercise we used only one. We strongly recommend using other indicators for regional, national and sub-national analyses of vulnerability.

Based on 3 criteria, we constructed 8 vulnerability domains:

Table 4.1. Vulnerability domains based on exposure, sensitivity and coping capacity.

Domain	Exposure	Sensitivity	Coping capacity
HHL	High	High	Low
HHH			High
HLL		Low	Low
HLH			High
LHL	Low	High	Low
LHH			High
LLL		Low	Low
LLH			High

The criteria and their thresholds

Exposure
We used the nine different climatic thresholds (see Section 1), with one addition to indicate climate change exposure. For each threshold, if there was no change or flip the area was classified as having low exposure; if there was a change or flip then exposure was called high.

For example: the reliable crop growing days flip (Map 4.1). Areas in red are 'high' exposure; everywhere else is 'low'.

Map 4.1. *Reliable crop growing days flip to less than 90 days.*

The different exposure metrics used are:
1. Lgpdelt: more than 5% decrease in length of growing period (LGP).
2. Lpgflip: LGP flips from more than 120 days to less than 120 days (threshold 1).

3. Rcgd: reliable crop growing days (RCGD) flip from more than 90 days to less than 90 days (threshold 2)
4. Tmax: maximum temperature flips from <30°C to > 30°C (threshold 4)
5. Tgrow: maximum temperature during the growing season flips from <30°C to > 30°C (threshold 5).
6. Rdaydec: rainfall per rainy day decreases > 10% (threshold 6)
7. Rdayinc: rainfall per rainy day increases > 10% (threshold 7)
8. CV: coefficient of variability of rainfall currently greater than 21%
9. Tmean: mean annual temperature flips from < 8°C to >8°C (threshold 3)

These each yield different exposure domains (see the maps in Section 2).

Sensitivity

Areas with more dependence on agriculture (both cropping and livestock based) are assumed to be more sensitive to a change in climate. Therefore, the greater an area is cropped (whether planted or grazed), the higher the sensitivity of that area. Based on the Ramankutty et al (2008) dataset we used percentage cropping as a proxy for sensitivity: areas having greater than 16% of the pixels were classified as under cropping (the mode for the global tropics) and considered highly sensitive (Map 4.2).
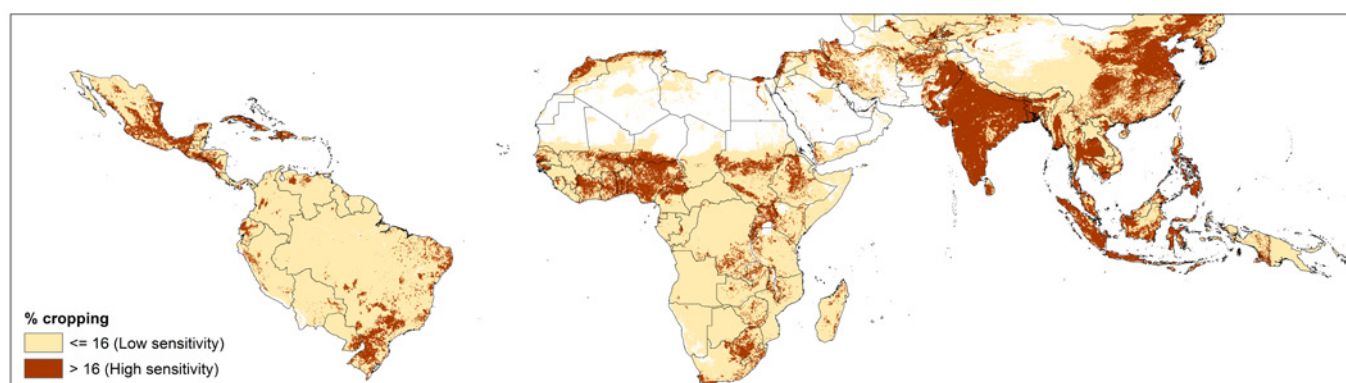
Map 4.2. *Areas with greater than 16% cropping (assumed sensitive to change in climate).*

Coping capacity

We considered that chronic food insecurity could be a proxy for coping capacity, as an inability to tackle chronic food insecurity indicates a number of institutional, economic and political problems. We used stunting with a threshold of 40% prevalence as the cutoff between high and low (maps for 30% and 50% also available) (Map 4.3). (Note that data are unavailable for a few countries, appearing as white in the domain maps.)
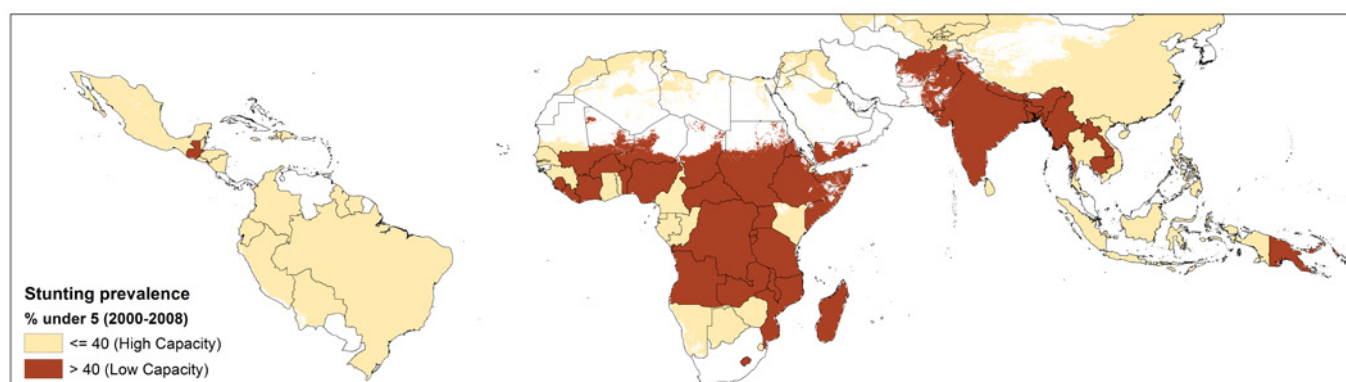
Map 4.3. *Areas with high and low coping capacity for a change in climate.*

The vulnerability domains, with different exposure variables

For each domain, we also calculated the vulnerable area (in km^2) and the number of vulnerable people (Map 4.4). The highest vulnerability is the domain HHL: high exposure, high sensitivity and low coping capacity. The least vulnerable is the domain LLH: low exposure, low sensitivity and high coping capacity. The red and orange colours are for the high exposure areas; green and blue are for low exposure. The paler colours are high capacity.
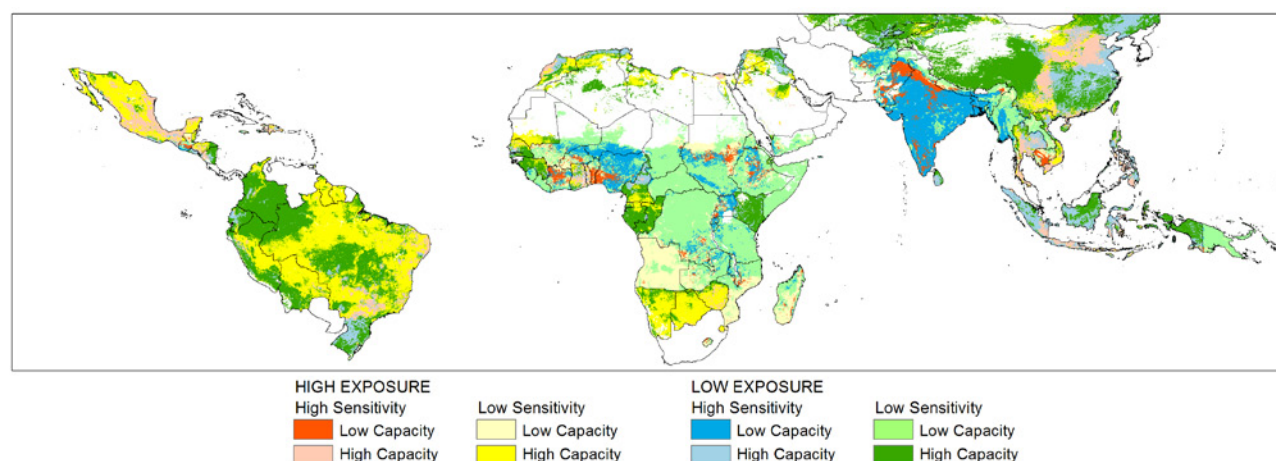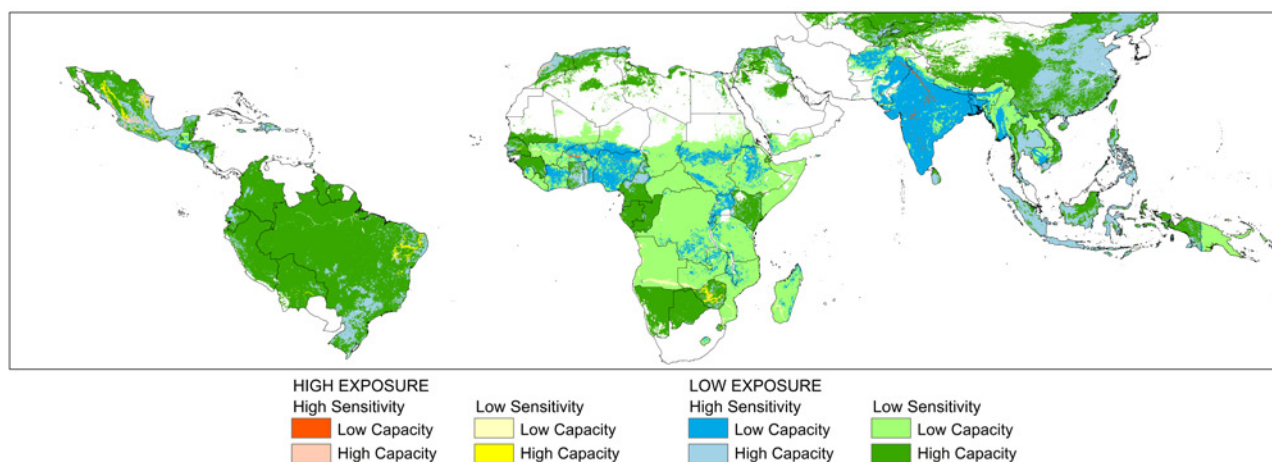

Map 4.4. Exposure 1: Areas where there is greater than 5% change in LGP.

This exposure threshold includes significant portions of the global tropics. Quite large parts of Latin America, Southern and West Africa, eastern China, Southeast Asia, and the northern part of south Asia fall into the high exposure categories. The number of people in the most vulnerable category (HHL) is 266 million and the area is about 1.4 million km^2.

Table 4.2. Area and population included in the vulnerability domain exposure 1

Domain	Area (000 Km²)	Population (million)
LLL	10,506	320.3
LLH	15,725	467.3
LHL	5,173	1151.9
LHH	5,076	875.5
HLL	3,652	111.7
HLH	10,577	289.5
HHL	1,412	265.7
HHH	3,322	734.1

HIGH EXPOSURE
High Sensitivity
- Low Capacity
- High Capacity
Low Sensitivity
- Low Capacity
- High Capacity

LOW EXPOSURE
High Sensitivity
- Low Capacity
- High Capacity
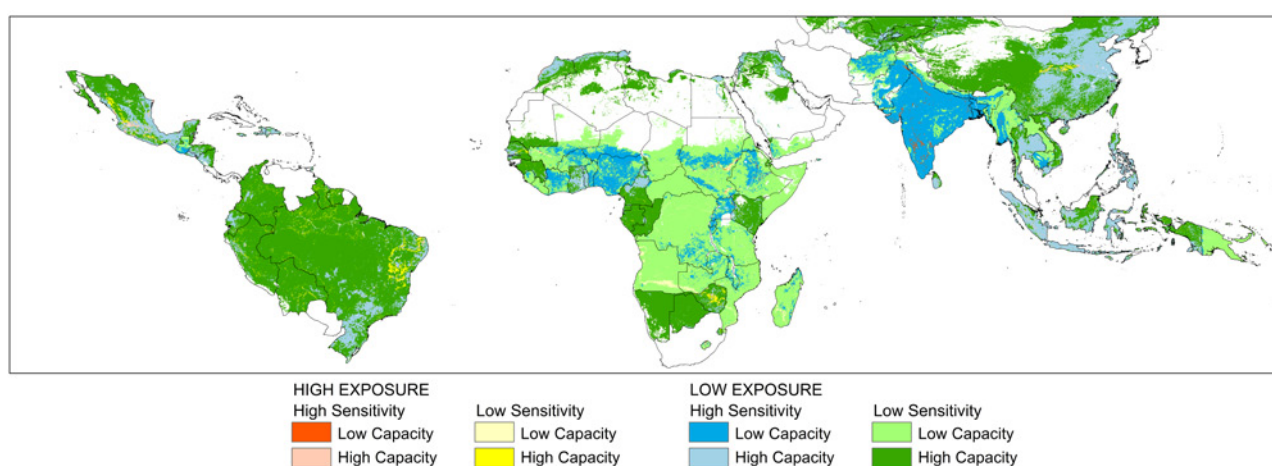Low Sensitivity
- Low Capacity
- High Capacity

Map 4.5. *Exposure 2: LGP flips from more than 120 days to less than 120 days.*

This is a more restrictive exposure threshold, with only a few areas in south Asia in the HHL category, parts of Mexico in the HHH category, and areas of Africa in the HLL category. The population in the HHL (most vulnerable) category is 25 million, covering an area of only 81,000 km^2.

Table 4.3. *Area and population included in the vulnerability domain exposure 2*

Domain	Area (000 Km²)	Population (million)
LLL	13,951	428.2
LLH	26,018	745.8
LHL	6,504	1392.6
LHH	8,248	1594.6
HLL	206	3.8
HLH	284	11.0
HHL	81	25.0
HHH	150	15.0

HIGH EXPOSURE
High Sensitivity
- Low Capacity
- High Capacity
Low Sensitivity
- Low Capacity
- High Capacity

LOW EXPOSURE
High Sensitivity
- Low Capacity
- High Capacity
Low Sensitivity
- Low Capacity
- High Capacity

Map 4.6. *Exposure 3: RCGDs flip from more than 90 days to less than 90 days (threshold 2).*

This exposure threshold includes a larger area, with more of each continent appearing in the high exposure category. However most of these areas are in the low sensitivity category, meaning less than 16% of the area is cropped. The population in the HHL category is 38.8 million.

Table 4.4. *Area and population included in the vulnerability domain exposure 3*

Domain	Area (000 Km²)	Population (million)
LLL	13,745	422.0
LLH	25,625	730.1
LHL	6,424	1378.8
LHH	8,129	1569.4
HLL	412	10.0
HLH	677	26.8
HHL	161	38.8
HHH	269	40.2
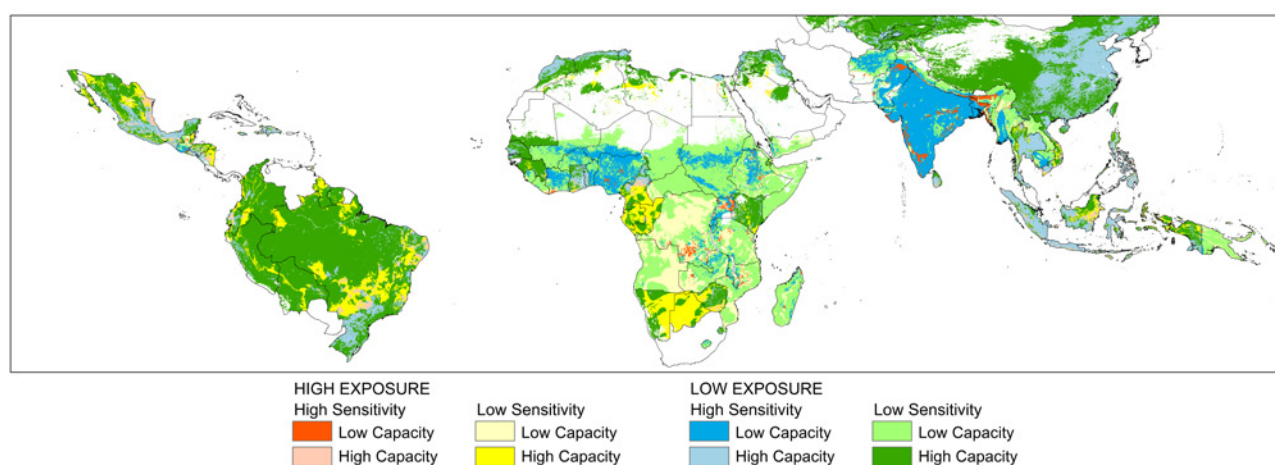
Map 4.7. *Exposure 4: Maximum daily temperature flips from < 30°C to > 30°C (threshold 4).*

This is a more inclusive exposure threshold, with more of the tropics appearing in the high exposure category, especially in Africa. Interestingly, most of India is not highly exposed under this threshold, although part of the Indo-Gangetic Plains is in the HHL category. The population in the HHL category is 136.2 million.

Table 4.5. *Area and population included in the vulnerability domain exposure 4*

| Domain	Area (000 Km²)	Population (million)
LLL	10,782	361.7
LLH	22,165	694.8
LHL	5,952	1281.4
LHH	7,440	1519.1
HLL	3,375	70.3
HLH	4,137	62.1
HHL	633	136.2
HHH	957	90.5
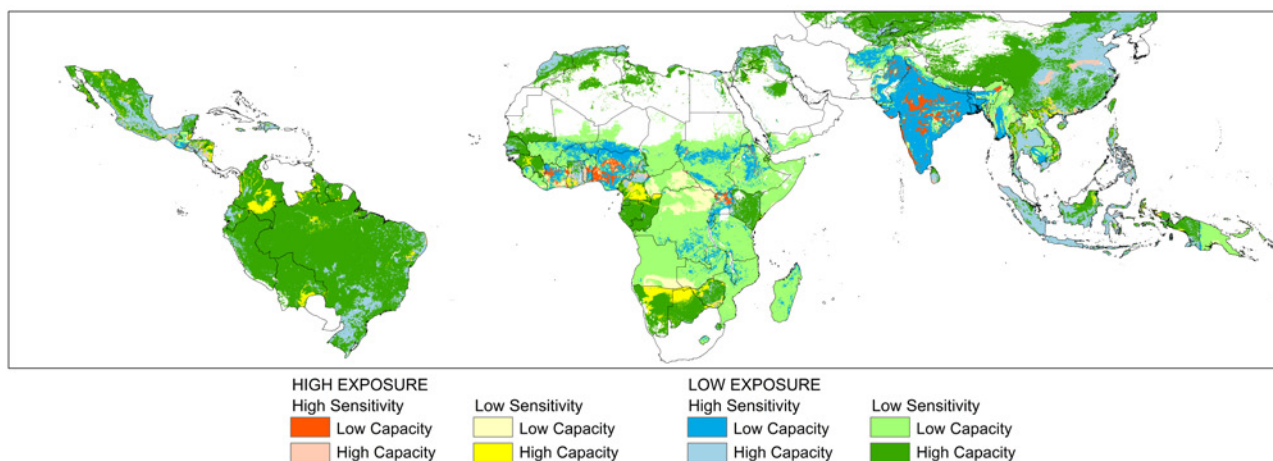
Map 4.8. *Exposure 5: Maximum daily temperature during the growing season flips from < 30°C to > 30°C (threshold 5).*

This category is obviously more restrictive than the previous thresholds. However new areas in India and China and West Africa, appear in the HHL or HHH categories, as well as Central America. The population in the HHL category is 170.5 million.

Table 4.6. *Area and population included in the vulnerability domain exposure 5*

| Domain	Area (000 Km²)	Population (million)
LLL	12,531	388.2
LLH	24,704	717.2
LHL	5,697	1247.1
LHH	7,873	1492.6
HLL	1,626	43.8
HLH	1,598	39.7
HHL	888	170.5
HHH	525	117.0
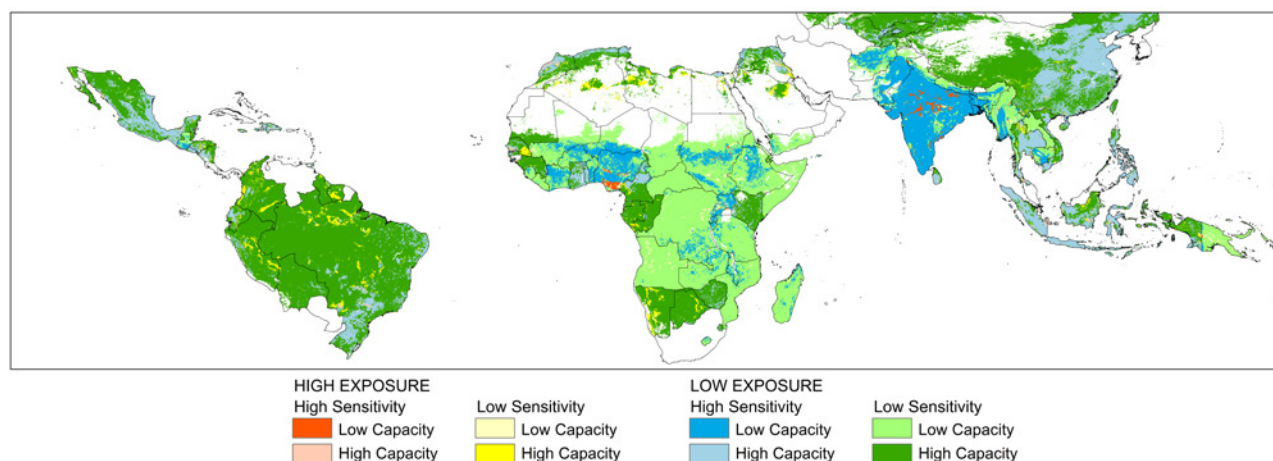
Map 4.9. *Exposure 6: Rain per rainy day decreases by more than 10% (threshold 6).*

This threshold is also quite restrictive in terms of land area, but it is interesting to note the areas in Nigeria and India that fall into the HHL category. The other highly exposed areas are largely in the low sensitivity domain, as not much is cropped. The population in the HHL category is 85 million.

Table 4.7. *Area and population included in the vulnerability domain exposure 6*

Domain	Area (000 Km²)	Population (million)
LLL	13,749	417.7
LLH	25,073	730.2
LHL	6,296	1332.6
LHH	8,097	1556.3
HLL	408	14.3
HLH	1,229	26.7
HHL	289	85.0
HHH	301	53.3
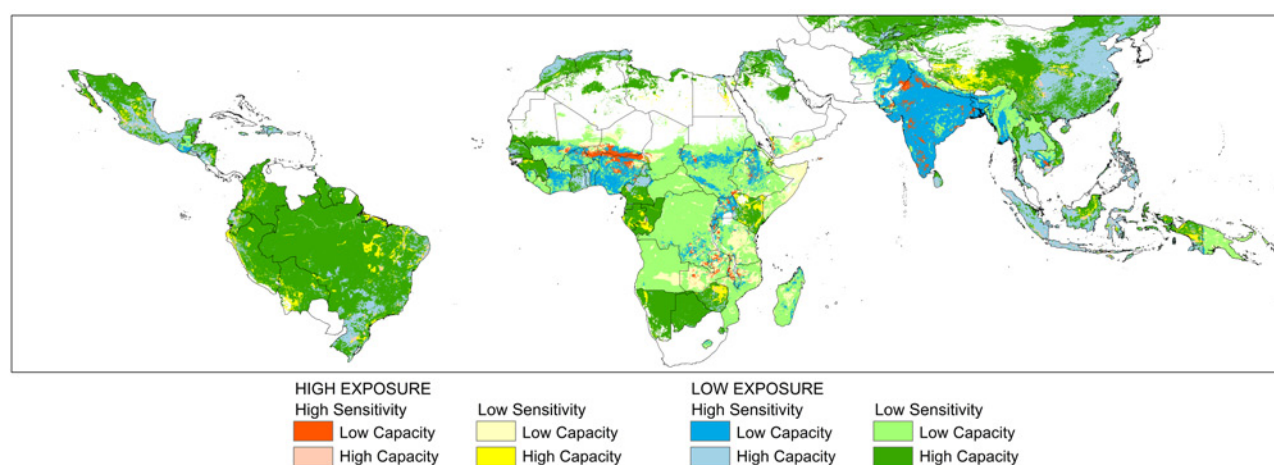
Map 4.10. *Exposure 7: Rain per rainy day increases by more than 10% (threshold 7).*

This exposure includes a number of more densely populated areas with low coping capacity, again in West and Southern Africa, and south and Southeast Asia. The vulnerable population is 138.4 million.

Table 4.8. *Area and population included in the vulnerability domain exposure 7*

| Domain	Area (000 Km²)	Population (million)
LLL	11,709	373.1
LLH	24,473	693.0
LHL	5,679	1279.2
LHH	7,911	1518.7
HLL	2,449	58.9
HLH	1,828	63.8
HHL	906	138.4
HHH	486	91.0
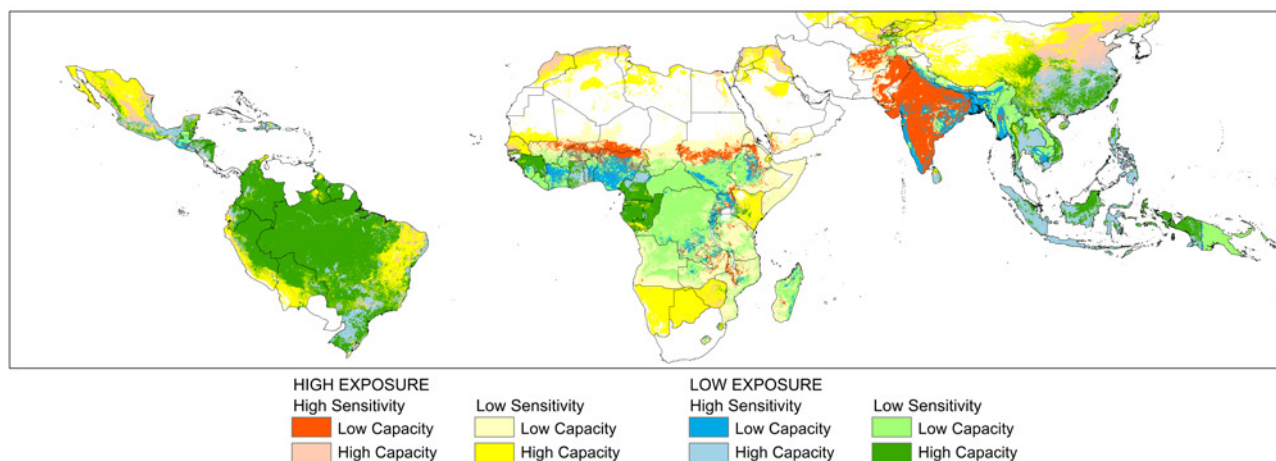
Map 4.11. *Exposure 8: CV rainfall currently greater than 21%.*

This is a very inclusive exposure threshold, with most of Africa and south and east Asia included in the high exposure category. The population in the HHL category increases to 842.3 million.

Table 4.9. *Area and population included in the vulnerability domain exposure 8*

Domain	Area (000 Km²)	Population (million)
LLL	7,298	237.0
LLH	13,337	442.6
LHL	2,614	575.3
LHH	4,519	871.6
HLL	6,859	195.1
HLH	12,965	314.2
HHL	3,971	842.3
HHH	3,878	738.0
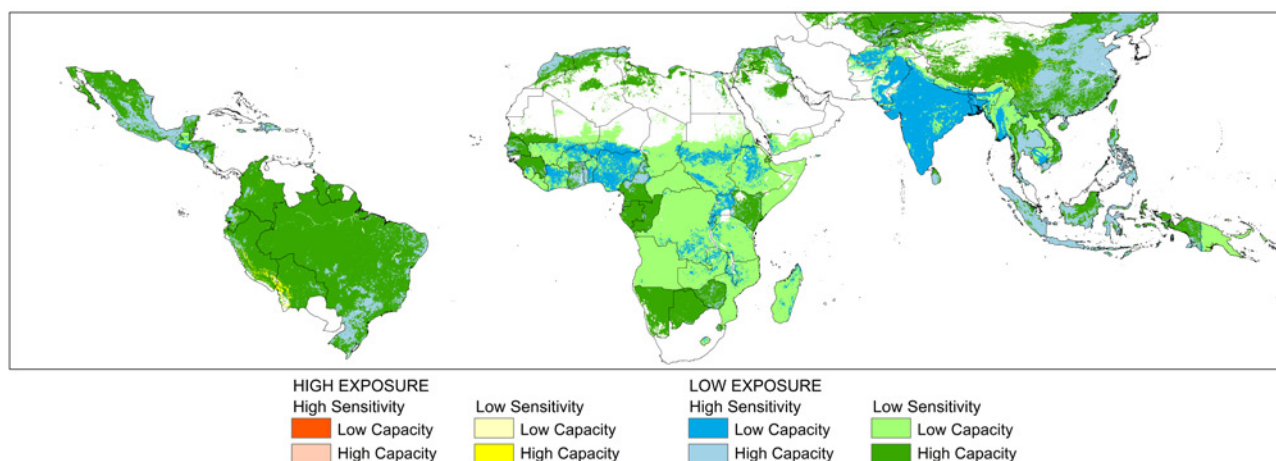
Map 4.12. *Exposure 9: Mean annual temperature flips from < 8°C to > 8°C.*

This is a different type of exposure from the other eight, as these areas represent a lifting of current temperature constraints (average temperature too low), and so cropping potential may increase. Thus the domains to focus on are HLH or HHH, on the map indicated by "positive change". The combined population in these two is 6 million and concentrated in the Andes and central China.

Table 4.10. *Area and population included in the vulnerability domain exposure 9*

| Domain	Area (000 Km²)	Population (million)
LLL	14,124	430.4
LLH	26,119	751.7
LHL	6,573	1417.2
LHH	8,380	1608.8
HLL	33	1.6
HLH	183	5.2
HHL	13	0.4
HHH	17	0.8

5. Regional maps

For targeting within regions, we also made regional maps, to highlight the variation within them (as opposed to among) more easily. Here we show the current CCAFS regions: East Africa, West Africa, and South Asia. The other regional maps are available as needed. The thresholds and food security indicators are as defined in the global maps.

East Africa
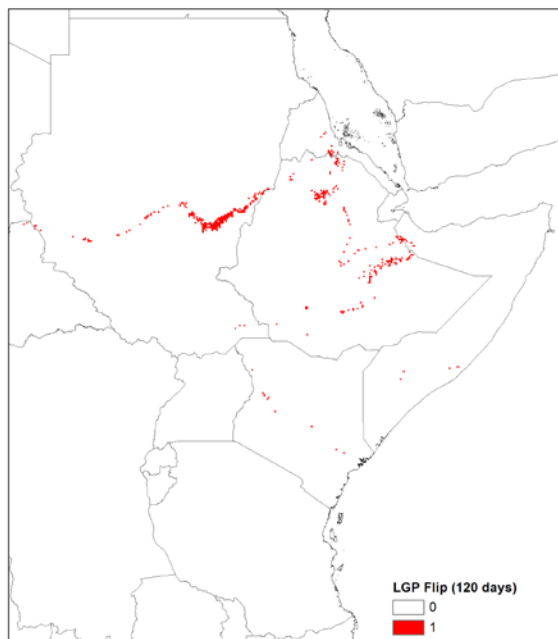
Map 5.1. *Threshold 1. Length of growing period flips from more than 120 days to less than 120 days.*
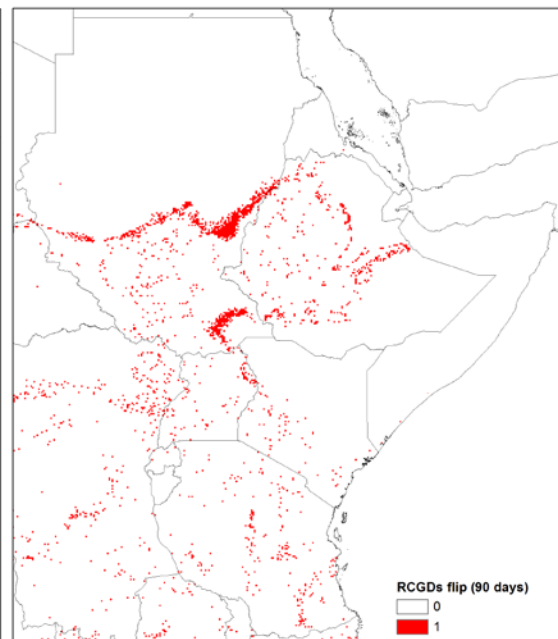
Map 5.2. *Threshold 2. Number of reliable crop growing days flips from more than 90 to less than 90.*

These maps (5.1 and 5.2) both indicate increased cropping risk. Threshold 2 (Map 5.2) includes a range of areas throughout East Africa.
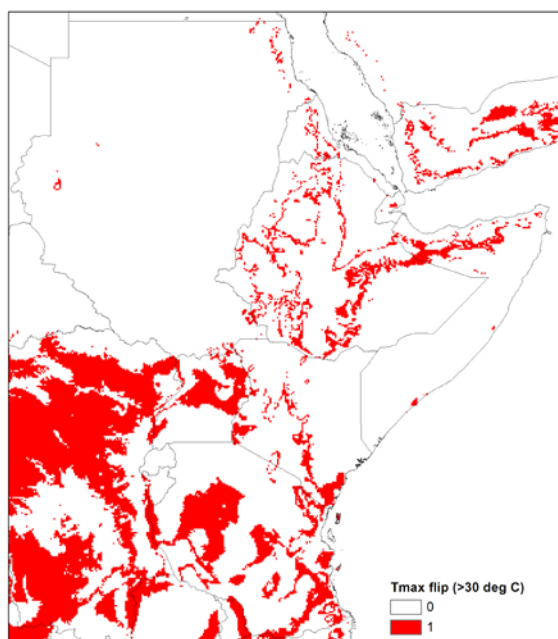
Map 5.3. *Threshold 4 (maximum temperature flips to > 30°C).*
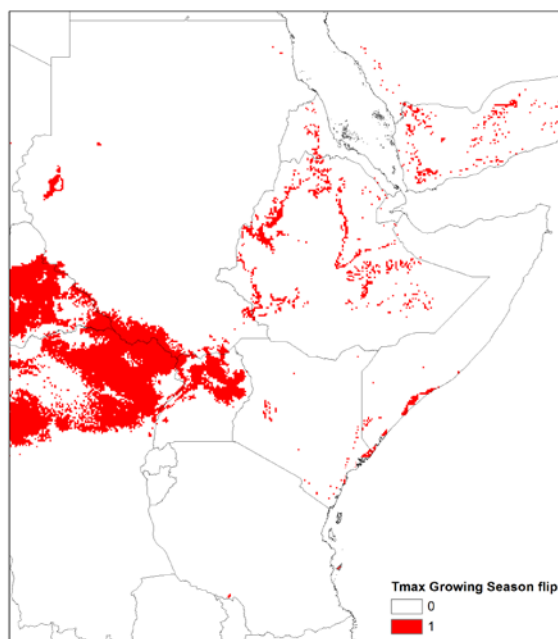
Map 5.4. *Threshold 5 (maximum temperature in the growing season flips to > 30°C).*
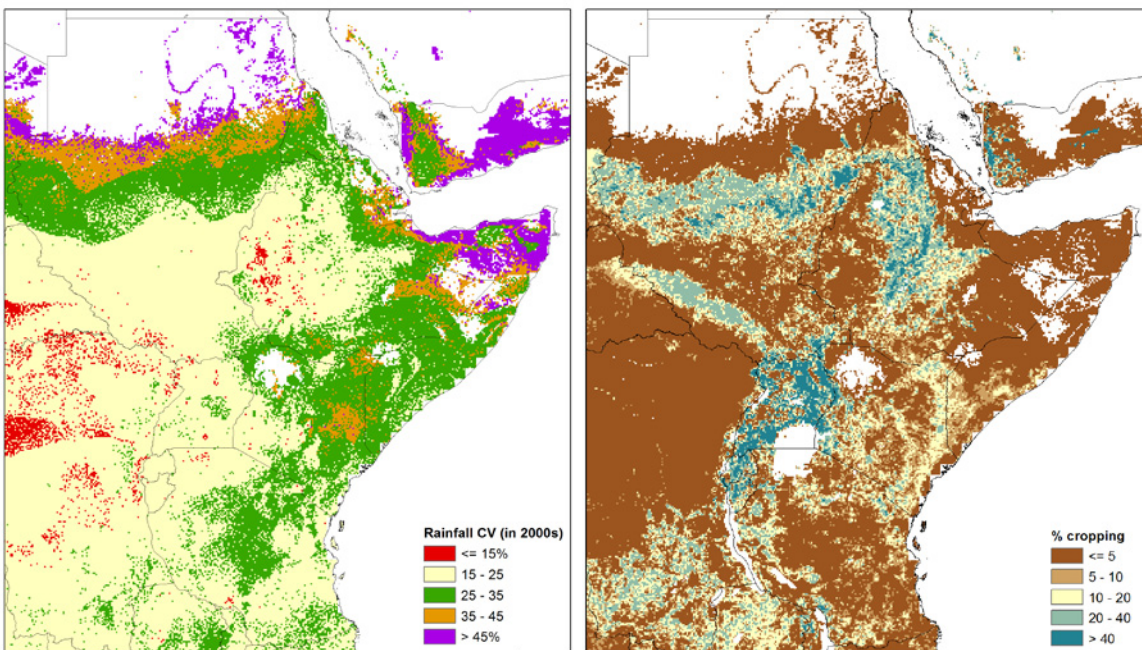
Threshold 5 (Map 5.4) is more restrictive, but northern Uganda, parts of Ethiopia and central Kenya are highlighted.
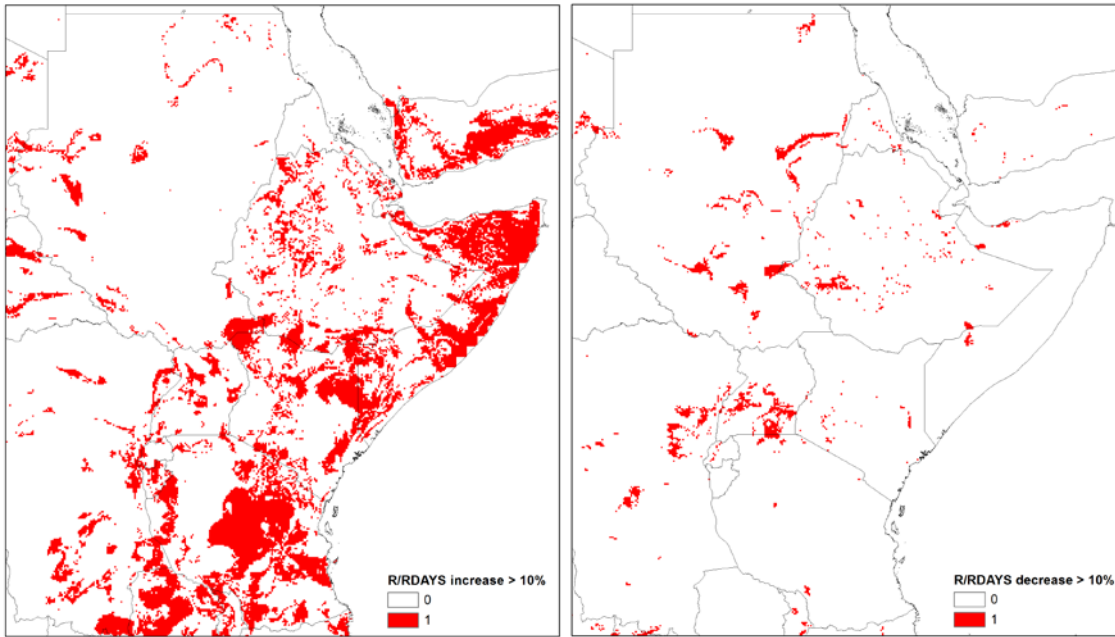
Map 5.5. *Threshold 6 (Average rainfall per rainy day increases by more than 10%).*

Map 5.6. *Threshold 7 (Average rainfall per rainy day decreases by more than 10%).*
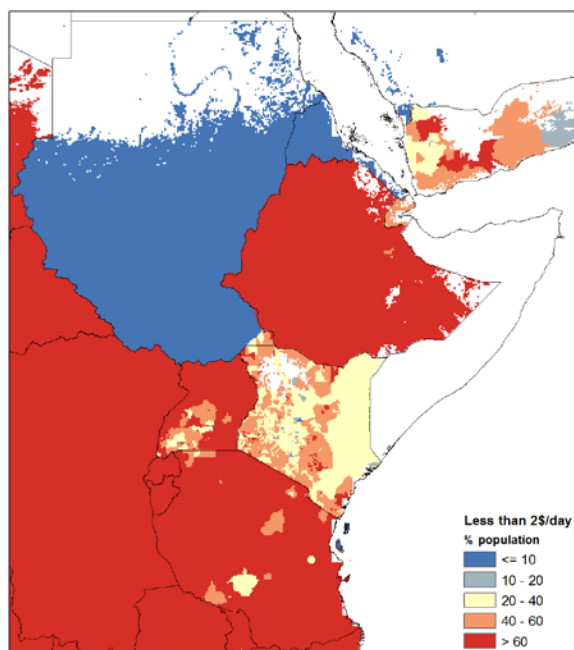
Threshold 6 (Map 5.5) is much more common than threshold 7 (Map 5.6).

Map 5.7. *Coefficient of rainfall variability (mode is 21% for global tropics).*

Map 5.8. *Percent area cropped.*

Note in Map 5.8 the high cropping density in southern Sudan, the highlands of Ethiopia and much of Uganda relative to Tanzania and Kenya. The eastern areas have higher CV of rainfall (Map 5.7).

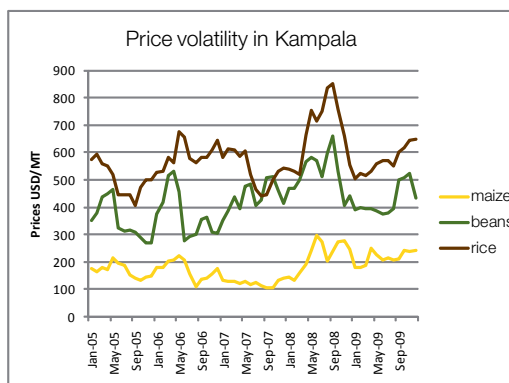**Map 5.9.** *Economic access: % population on less than USD 2 a day.*
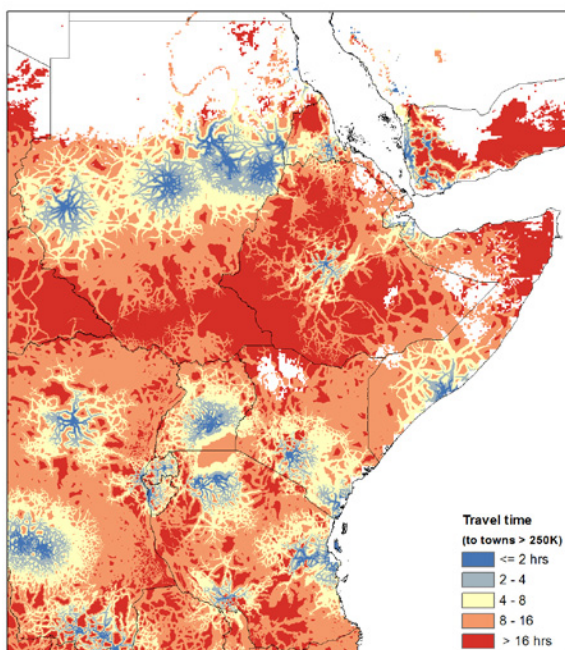
Map 5.10. *Physical access: travel time to nearest town > 250K.*
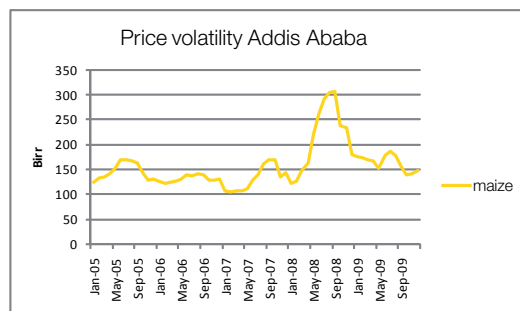
Kenya has lower poverty rates than Ethiopia, Tanzania, Uganda, Burundi and Rwanda (Map 5.9).
Physical access is restricted in much of Ethiopia, north Kenya, north Somalia and parts of Tanzania (Map 5.10).
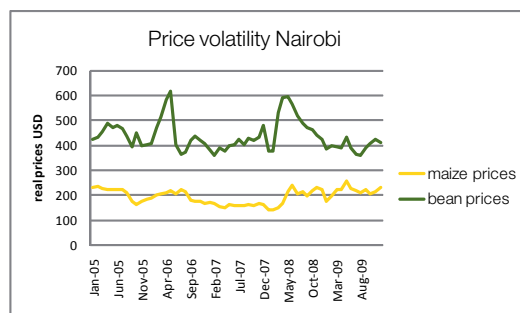
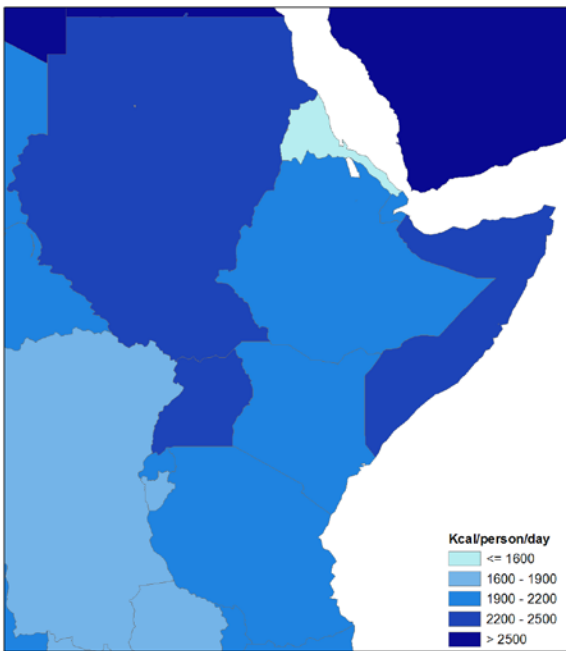**Figure 5.1.** *Price volatility Nairobi.*

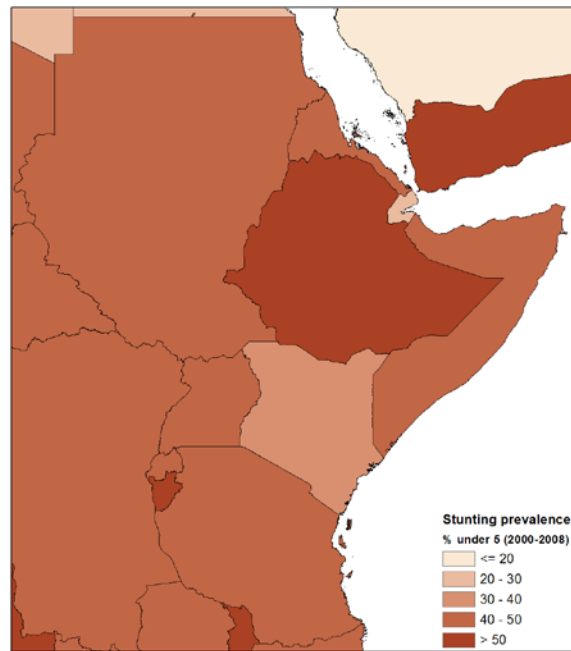**Figure 5.2.** *Price volatility Kampala.*

Figure 5.3. *Price volatility Addis Ababa.*

Figures from 2005 to 2009; prices are adjusted for inflation.

Maize prices are more stable than bean or rice prices. All three graphs show the 2008 price spike.
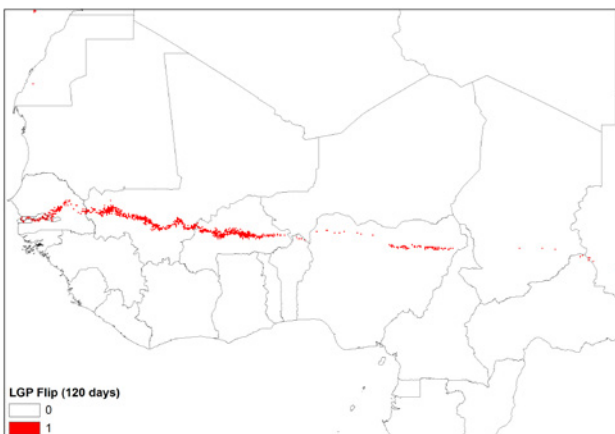
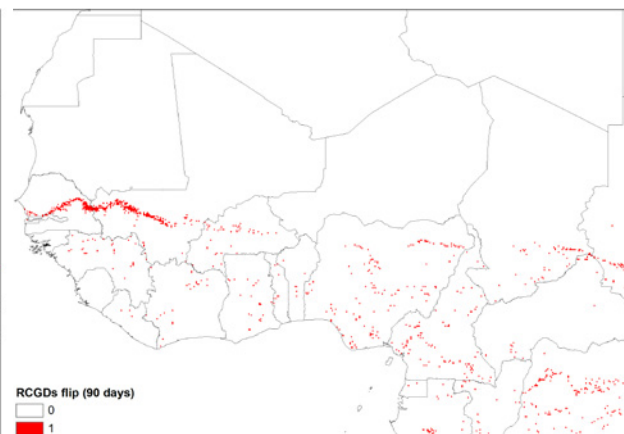**Map 5.11.** *Kilocalories available per person per day.*

Map 5.12. *Stunting prevalence (% under five).*

Kilocalorie availability is lower in Uganda, Sudan and Somalia (Map 5.11). However stunting prevalence is highest in Ethiopia, followed by Burundi. Kenya has the lowest stunting prevalence (Map 5.12).
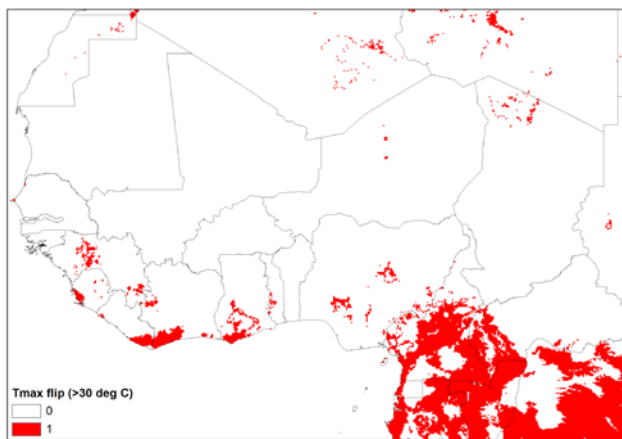
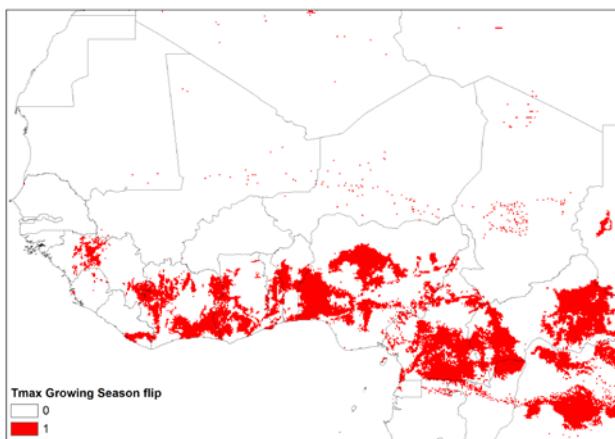# West Africa

Map 5.13. *LGP flip.*

Map 5.14. *RCGD flip.*

Thresholds 1 and 2. The length of growing period flip is restricted to a band across Senegal, southern Mali and Burkina Faso, with a bit in north Nigeria (Map 5.13). RCGD flip includes many more scattered areas throughout the region south of the Sahara (Map 5.14).
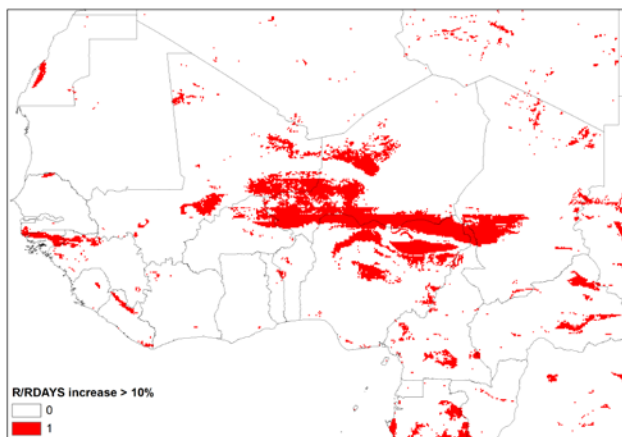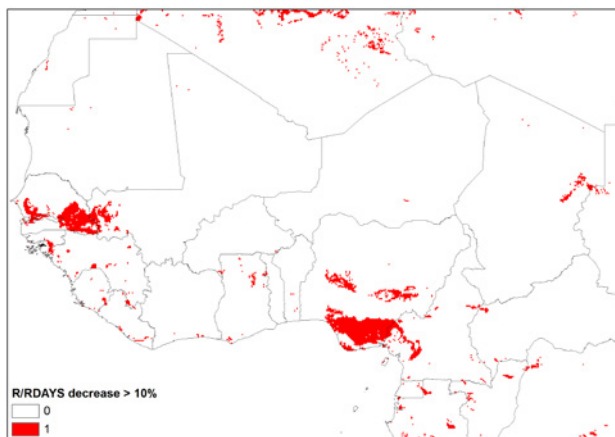
Map 5.15. *Tmax flip.*

Map 5.16. *Tmax growing season flip.*

Thresholds 4 (Map 5.15) and 5 (Map 5.16). Threshold 5 is common in the southern parts of the region, along the coast, much of Cameroon and the Central African Republic. Note that this overlaps with intensive cropping.
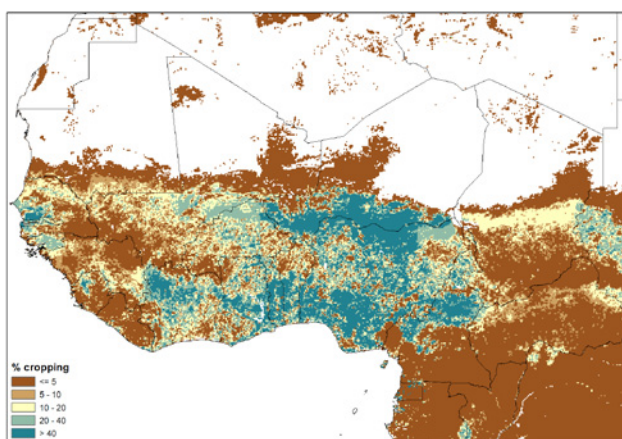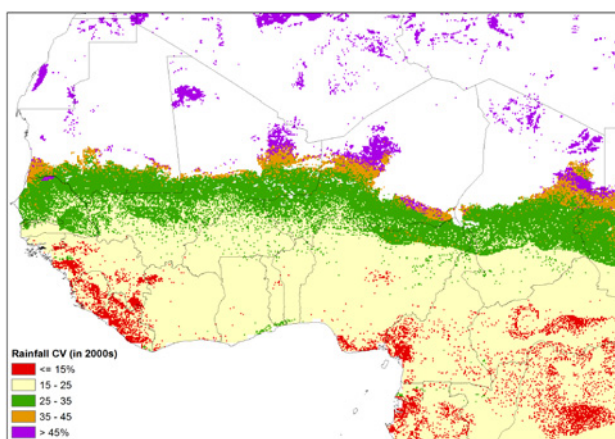

Map 5.17. *Rainfall per rainy day increase.*

Map 5.18. *Rainfall per rainy day decrease.*

Thresholds 6 and 7. Rainfall intensity may increase in the northern areas of Nigeria and much of Niger (Map 5.17). Rainfall per rainy day may decrease in the lower parts of Nigeria and across central Senegal (Map 5.18).

Map 5.19. *Percent area cropped.*

Map 5.20. *Coefficient of rainfall variability - mode is 21% for global tropics.*

The CV of rainfall increases as one moves north (Map 5.20); some of this area is currently cropped quite intensively along the Niger/Nigeria border (Map 5.19). Map 5.19 also shows the intensive cropping throughout Nigeria, Ghana, Togo, Benin and Cote D'Ivoire, as well as northern Cameroon and eastern Senegal and the Gambia. Many of the climate change exposure thresholds coincide with these areas. It is notable the LGP flip is concentrated in the high CV rainfall band.
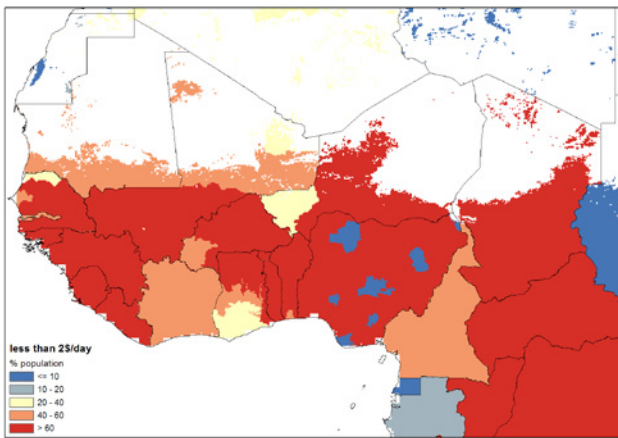
Map 5.21. *Economic access: % population on less than USD 2 per day.*
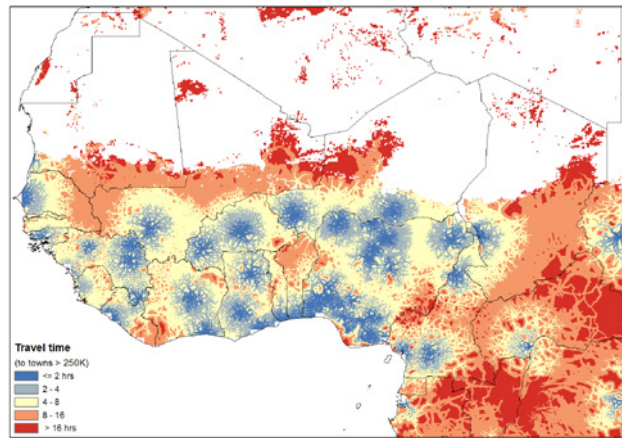
Map 5.22. *Physical access: travel time to nearest town > 250K.*

As seen in Map 5.21 there are high concentrations of poverty across the region. The difference between urban and rural areas in Nigeria is stark while Cote d'Ivoire and Cameroon are wealthier. There are also sub-national differences in Nigeria, Mali, Burkina Faso and Ghana. Physical access is good in many of the cropped areas of the region (Map 5.22).
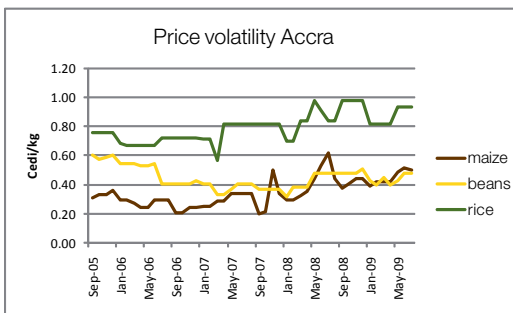
Figure 5.4. *Price volatility Accra.*
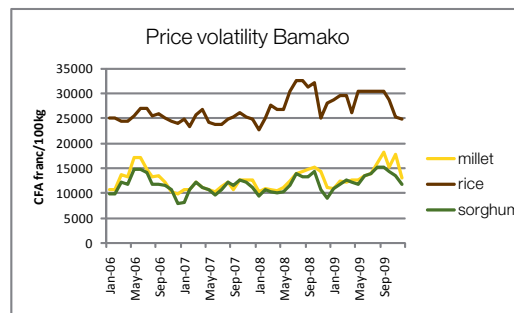
Figure 5.5. *Price volatility Bamako.*
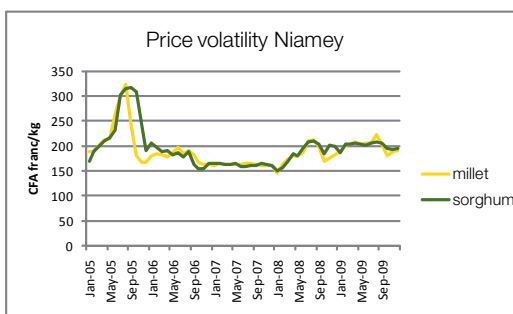
Figure 5.6. *Price volatility Niamey.*

The spike of 2005 was huge in Niamey, even relative to 2008 (Fig 5.6).
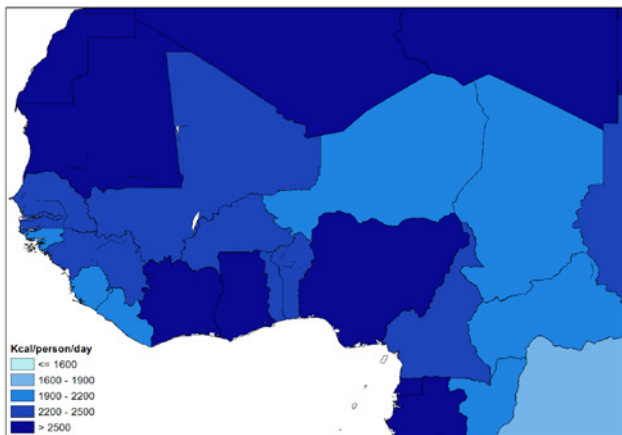
Map 5.23. *Kilocalories available per person per day.*
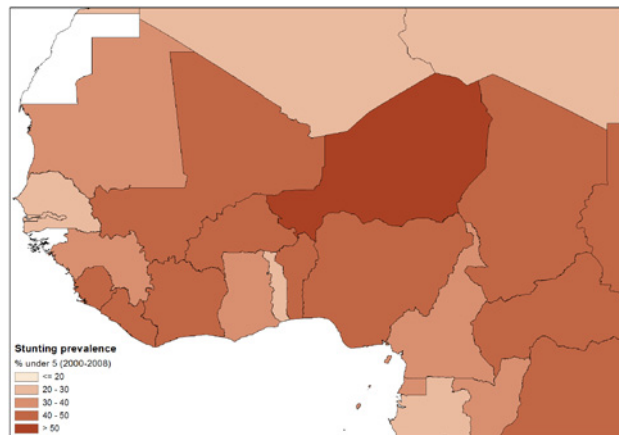
Map 5.24. *Stunting prevalence (% under five).*

As seen in Map 5.23 kilocalorie availability is lowest in Chad, Niger, and the Central African Republic. Stunting (Map 5.24) is over 50% in Niger and is greater than 40% in Nigeria, Togo, Cote d'Ivoire, Liberia, Sierra Leone, Mali, Chad and the Central African Republic. Senegal, the Gambia and Benin have rates of 20% or lower.

South Asia
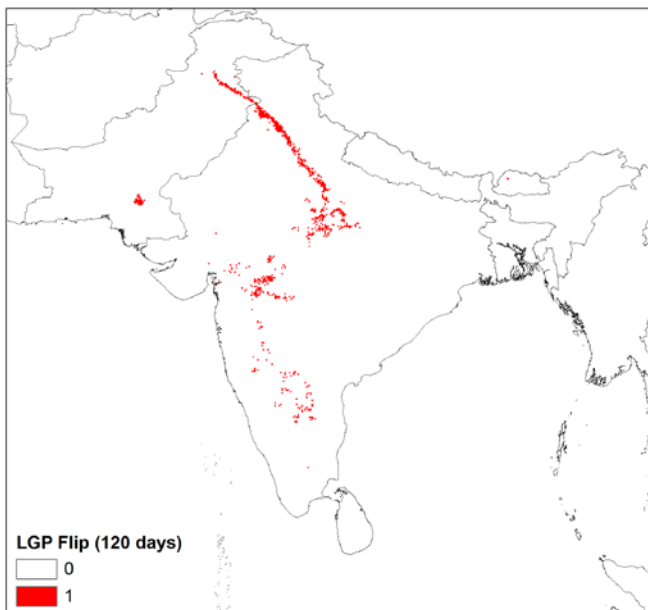
Map 5.25. *LGP flip.*
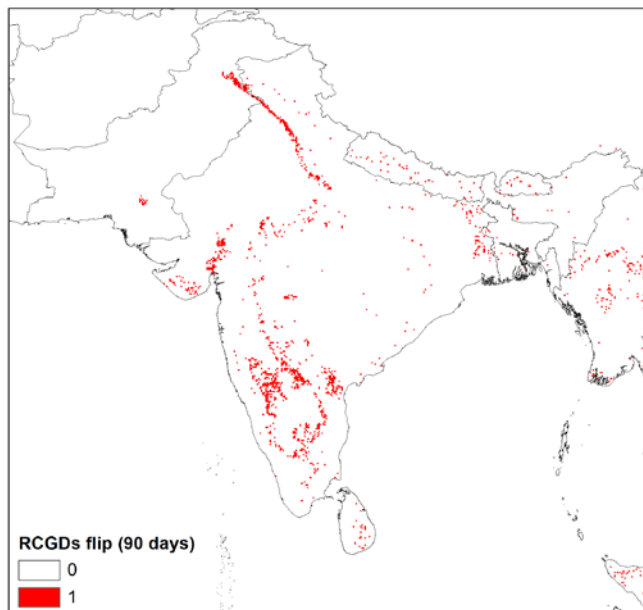
Map 5.26. *RCGD flip.*

Thresholds 1 and 2. As in the other regions, the LGP flip is the most restrictive threshold, with concentrations in the Indo-Gangetic Plains, southern Pakistan, and western India (Map 5.25). The RCGD flip includes more of south India, Nepal, and west India (Map 5.26).
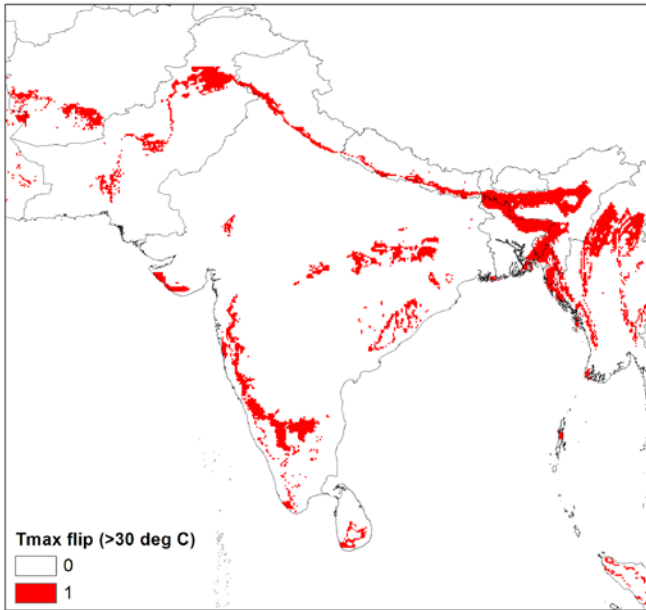
Map 5.27. Tmax flip.
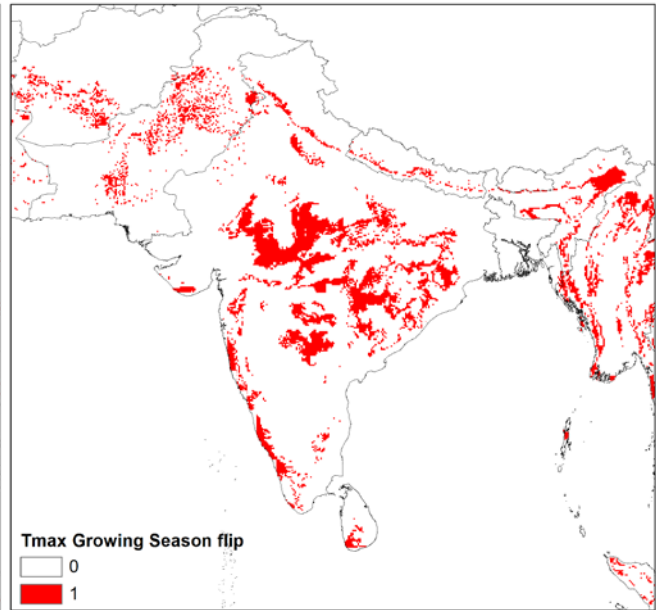
Map 5.28. Tmax growing season flip.

Thresholds 4 and 5. Tmax flip covers central Pakistan, the northern Indo-Gangetic Plains, and parts of east and west India (Map 5.27). Tmax growing season flip is more extensive across central India, Pakistan, the northern Indo-Gangetic Plains, and eastern India (Map 5.28).
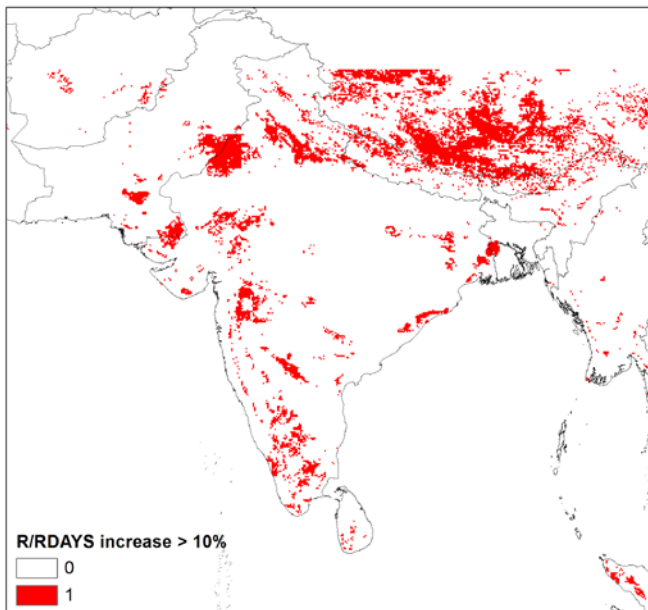
Map 5.29. Rainfall per rainy day increase.
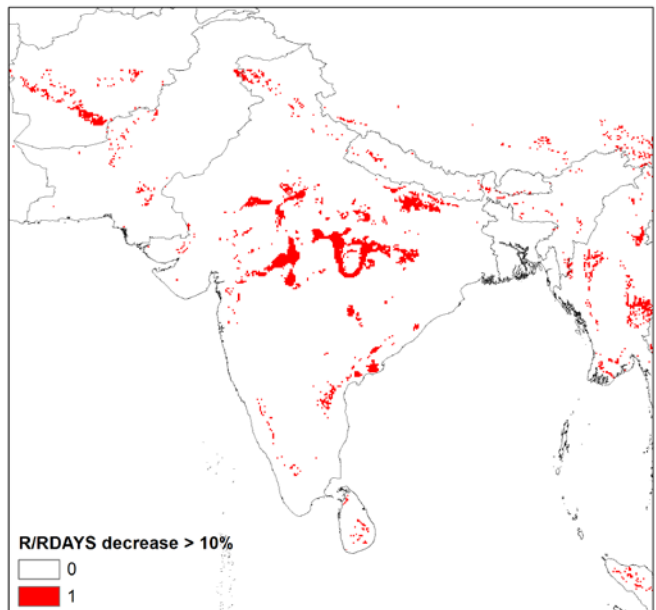
Map 5.30. Rainfall per rainy day decrease.

Threshold 6 and 7. Rainfall intensity is likely to increase in western India, Nepal and parts of east India (Map 5.29). Central and north India are likely to see decreases in rainfall amounts per rainy day (Map 5.30). Bangladesh is not highlighted under any of the thresholds.
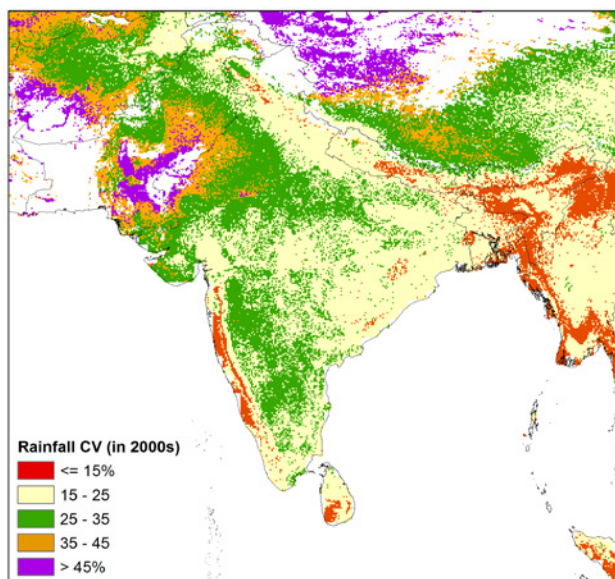
Map 5.31. *Coefficient of rainfall variability.*
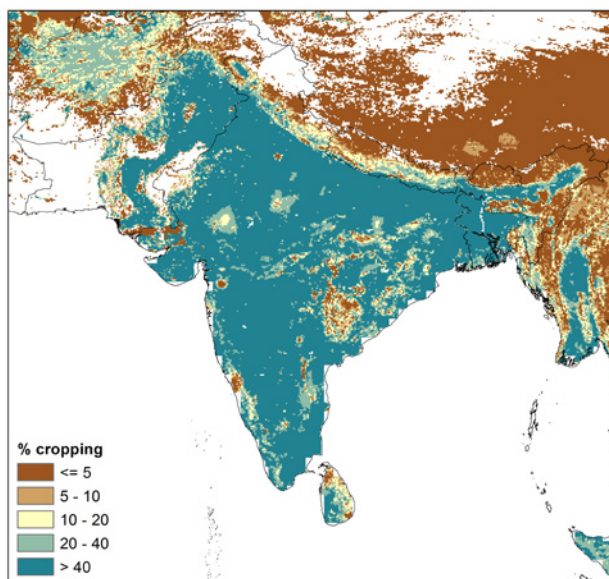
Map 5.32. *Percent area cropped.*

India, Pakistan and Bangladesh are all intensively cropped (Map 5.32). Pakistan already has very high CV of rainfall, along with northwest and south India (Map 5.31).
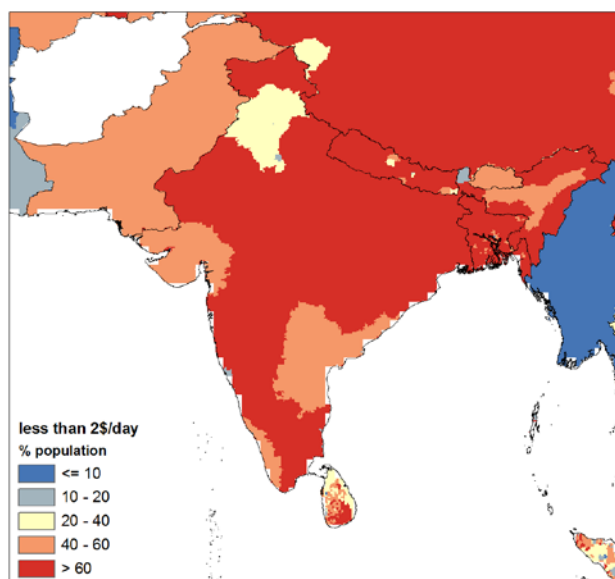
Map 5.33. *Economic access: % population on less than USD 2 per day.*
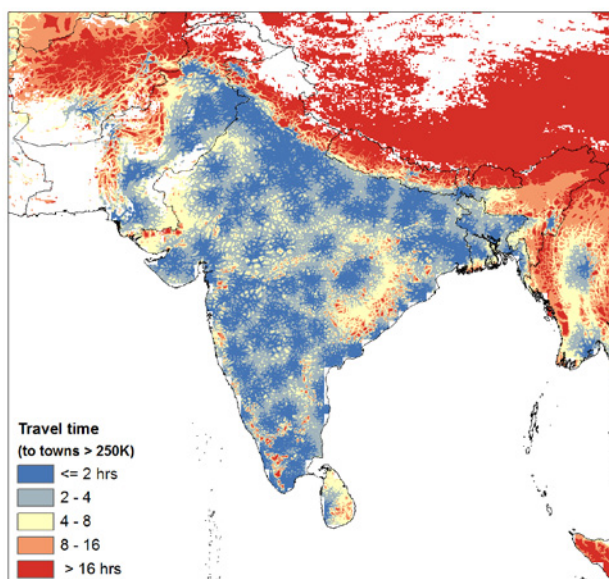
Map 5.34. *Physical access: travel time to nearest town > 250K.*

Nepal, Bangladesh and much of India have greater than 60% of the population living on less than USD 2 per day (Map 5.33). Bangladesh, India and central Pakistan are highly urbanized (5.34), in contrast to Nepal Map.
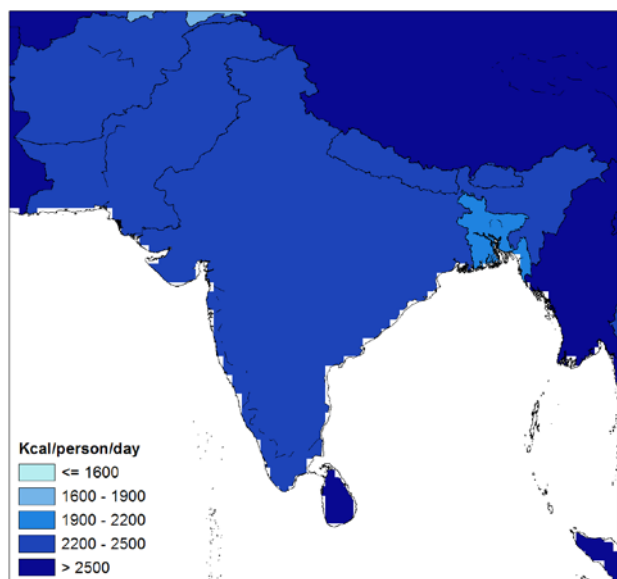
Map 5.35. *Kilocalories available per person per day.*
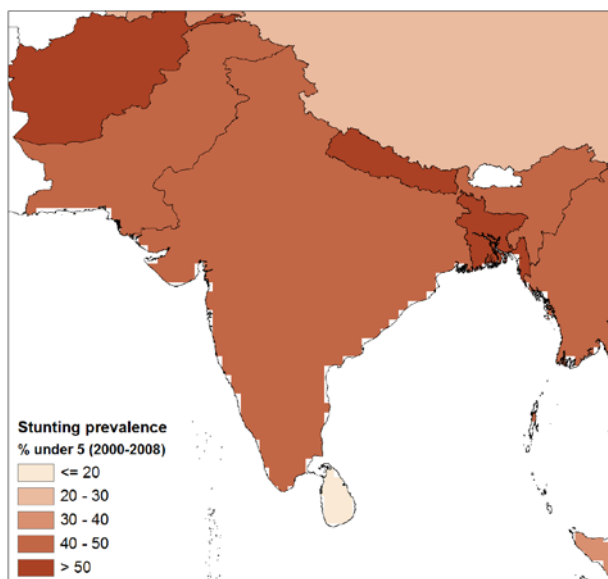
Map 5.36. *Stunting prevalence (% under five).*

Bangladesh has the lowest kilocalorie availability in the region (Map 5.35) while Bangladesh and Nepal have stunting prevalence over 50% (Map 5.36).

Price volatility 2005-2009 (real prices)
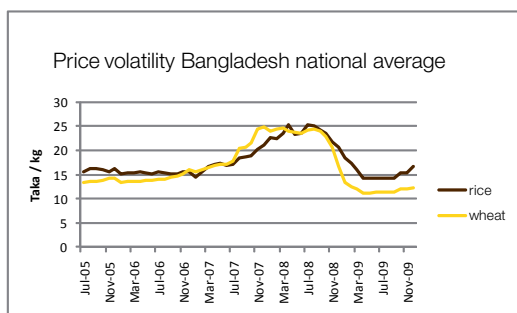
Figure 5.7. *Price volatility Bangladesh.*
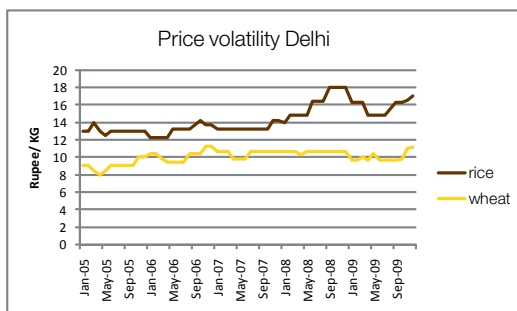
Figure 5.8. *Price volatility Delhi.*

Wheat prices are very stable in Delhi, rice less so. Bangladesh was clearly affected by the 2008 price spike.

Conclusion: Analysis of hotspots and implications for CCAFS research

This project set out to identify hotpots of food insecurity and climate change. We have done this for the global tropics as a whole, as well as within specific regions, including those currently targeted by the CCAFS programme.

Climate change hotspots
Nine climate change thresholds were defined. The major implications of these are:

- Length of growing period declines by 5% or more across a broad area of the tropics, including heavily cropped areas of Mexico, Brazil, Southern and West Africa, the Indo-Gangetic Plains, and Southeast Asia. This suggests that at a minimum, most of the tropics will experience a change in growing conditions that will require adaptation to current agricultural systems.

- Length of growing period flips to less than 120 days in a number of locations across the tropics, notably in Mexico, northeast Brazil, Southern and West Africa and India. This is a critical threshold for a number of crops as well as rangeland vegetation, and hence these areas are important to target for high exposure to climate change.

- Reliable crop growing days decrease to critical levels below which cropping might become too risky to pursue as a major livelihood strategy in a large number of places across the global tropics, including West Africa, East Africa, and the Indo-Gangetic Plains. If we use this threshold as an indicator of where CCAFS might move next, there are large and troubling areas in Southern Africa, south India, northeast Brazil, and south Mexico. There is good consensus from the various GCMs used (i.e., these results are robust) for West Africa, the Indo-Gangetic Plains, parts of East Africa, and much of Southern Africa and south India. These results seem to be less robust for south Mexico, northeast Brazil, and parts of East Africa (Kenya, specifically).

- High temperature stress (above 30°C) will be widespread in East and Southern Africa, north and south India, Southeast Asia, northern Latin America and Central America. During the primary growing season high temperature stress will be a problem for different areas. These are also important high exposure thresholds, but their implications should be considered in conjunction with cropping system type, dependence upon agriculture, and disease threats.

- Much of the tropics already experiences highly variable rainfall, above the median of 21% for cropped areas. Thus any increase in this variability will make agriculture riskier.

- Reduced rainfall per rain event can be compared to the current drought risk map; it appears that a number of current drought prone areas are included here, such as Southern Africa, West Africa and Central America; however, new areas may also become more drought prone, such as central India.

- A third, different type of hotspot relating to threshold 7, is the increase in rainfall intensity, although without more analysis it is not so easy to interpret what this may mean. East Africa, the Indo-Gangetic Plains, and parts of West Africa may be prone to increased erosion and runoff; these problems may be widespread in Southern Africa and throughout the neotropics. Some of these areas (eastern India and Bolivia) are currently flood prone.

- When eight of the thresholds were combined, Southern Africa emerged as highly exposed under several thresholds, as did selected areas in each of the regions, including northeast Brazil, Mexico, Pakistan, India and Afghanistan.

Food security hotspots
Eight food security indicators were mapped to identify current food insecurity hotspots. At least two indicators were chosen for each component of food security.

- Availability: bean, millet and sorghum yields are low throughout the areas of interest, although millet and sorghum are important dryland crops. The story for maize, wheat and rice is more mixed, but most of Africa (except Southern) has low yields relative to Latin America and southern India. The net food production index is stagnant in all areas of interest, with differences between countries rather than by region.

- Access: GDP per capita is low in many countries in Africa, as well as Afghanistan, Nepal, Bangladesh, Laos and Cambodia. Hotspots for poverty are West, Central and East Africa, India and Bangladesh and Southeast Asia. These are national level indicators. Travel time to markets indicates population density as well as infrastructure and urban growth. Regional differences emerge in this map.

- Utilization: Africa and south Asia are clearly much more chronically food insecure regions than Latin America or China. We have no data for food preferences, nor did we map sub-national data, which would be more helpful for targeting.

- In terms of resource pressure, again Africa is highlighted for population growth rates. Arable land per capita really differs by country.

Vulnerability domains

The implications of the nine vulnerability domains are as follows:

the most vulnerable domain for most exposures is high exposure, high sensitivity and low coping capacity (HHL). Such areas are highly exposed to climate change and have significant agriculture and high levels of food insecurity. However, we have used the same coping capacity threshold (40% stunting) in all domains. Thus the HHH category is also one to watch, as there are places with other types of food insecurity (such as constrained market access and poverty) and hence low coping capacity. Also, if we used 30% stunting instead, a number of other countries would be included, for example Kenya. Areas in the HLL capacity should also be carefully considered; if agriculture expanded or intensified in these areas their sensitivity could increase.

For now, areas in the low exposure domain are not a priority for CCAFS, but there is considerable variation in the definition of these domains by the exposure thresholds. Thus about half of the tropics are included in high exposure for "CV rainfall currently greater than 21%". This contrasts with the most restrictive threshold, "LGP flips from more than 120 to less than 120 days". The category to scrutinize is LHL, as these regions are highly sensitive due to having a significant amount of cropped area and being chronically food insecure.

Under exposure 1 (LGP decreases more than 5%), 265.7 million people are in the HHL category. For exposure 2 (LGP flips) HHL is very small in terms of people; most people are in the categories LHL or LHH. Exposure 3 (reliable crop growing days - RGCP flips) has about 14 million more people in the HHL category, but again most people are in LHL or LHH. Under exposure 4 (maximum temperature flips), the vulnerable population more than triples relative to exposure 3. Under exposure 5 (maximum temperature during the growing season flips) again more people are in the vulnerable categories. Under exposure 6 (rain per rainy day decrease), the most vulnerable population drops to 85 million, while under exposure 7 (rain per rainy day increase) 138.4 million are in the HHL category. This suggests that the choice of domain variables makes a big difference in terms of areas included.

Limitations to this analysis:

As with any exercise of this nature, there are a number of 'health warnings' to observe. First, these maps only cover current food security, as we are not working with a model that could give us predictive capacity to estimate future food security in the areas of interest. Second, we have primarily used national level food security data, which is a) not always reliable and b) masks within-country variation as well as within-household variation, the latter important to understand the social dimensions. Third, we have not mapped the links between climate change exposure and other food security variables besides crop yields (directly) and utilization (indirectly).

Next steps: there are several next steps that could be taken to improve on the mapping work done here.

1. Vary the indicators for coping capacity and sensitivity. Sensitivity varies by type of cropping system, just as food security impacts differ depending upon the aspect considered.

Use household food security data, such as that collected by the Food Economy Group or NGOs like Save the Children or CARE, to simulate or evaluate the household level food security impacts of climate change. This is best done as part of regional scenario exercises that include vulnerability analysis, both currently and under different scenarios of adaptive capacity.

2. Explore disease interactions with climate change.

3. Map drivers of food security and food system vulnerability rather than food security outcomes, using the IPCC framework of exposure, sensitivity and adaptive capacity.

4. Model food security to 2050 under a couple of key scenarios including one or more of the following key drivers (in addition to climate change):
   • Transformation of the rural economy is a key issue: what will the structure of agriculture look like under high urban migration?
   • High versus low economic growth and impacts on adaptive capacity.
   • Government versus private sector as key actors shaping innovations, etc. in food systems.
   • Regionalization versus globalization of markets.

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Appendix I: Food security indicators database

http://ccafs.cgiar.org/resources/climatehotspots

# Appendix 2: Probability maps of climate change thresholds

This appendix presents probability maps of the eight different thresholds as projected by the GCMs used, (the missing threshold is for annual CV of rainfall, which we are not able to project into the future in any meaningful way). Rather than using the mean climatology for the 2050s as projected in response to the A2 SRES scenario (Section 2 of the main report), here we have calculated the probability that each pixel in the global tropics will reach the respective threshold. It should be pointed out that for this study we had access to appropriate data from only four GCMs, but the same maps could be generated for a much larger sample of the 21 or so GCMs that went into the AR4, if the data were available.

Taking the maximum temperature threshold during the growing season as an example, the maps can be interpreted as follows. The darkest red areas are areas where all four models used in the analysis agreed on the temperature flip. It can be seen that there are several areas, such as southern Colombia and large areas in West, Central and southwest Africa, where the models agree, and (at least from this subsample of climate models) the result is robust – that is, it does not matter which climate model is used. There are other widespread areas in this map where there is less agreement: for northeast Brazil and large parts of East Africa, for example, only 1, 2 or 3 of the GCMs project this temperature flip. In such cases, the results are less robust, in that it does matter which climate model is used for a specific analysis. In addition there are large parts of the global tropics where this threshold is not projected to be attained by any of the models; Tanzania, for example, is projected to avoid this growing-season maximum temperature flip.

Two points might also be made. First, there are some differences between the use of an 'average' climatology to derive the threshold maps in Section 2 with the probability maps shown here. Second, the temperature-related thresholds tend to have less uncertainty associated with them (that is, the between-model variation is muted and the maps are darker brown) than the rainfall-related thresholds. This again highlights the need for caution in interpreting the threshold maps and for recognising that between-model differences may be important sources of uncertainty in some regions of the global tropics.
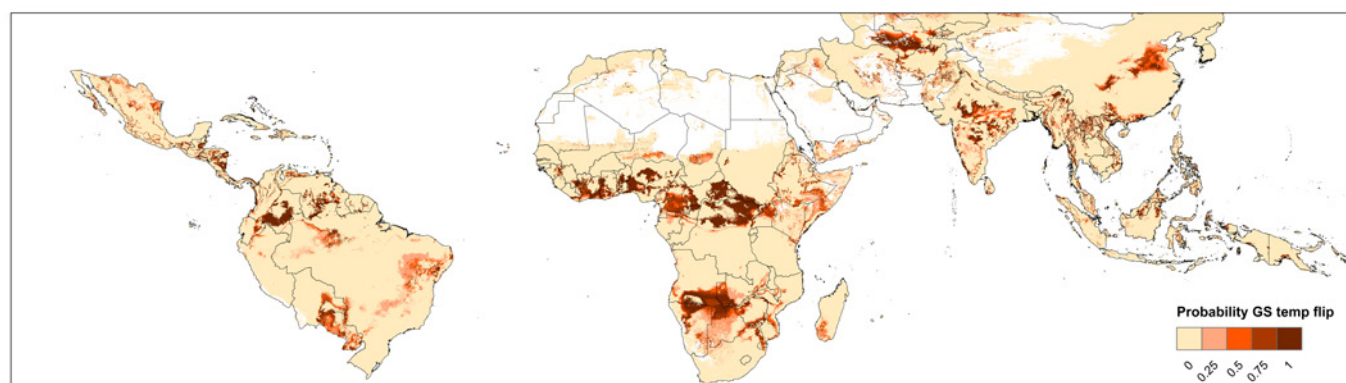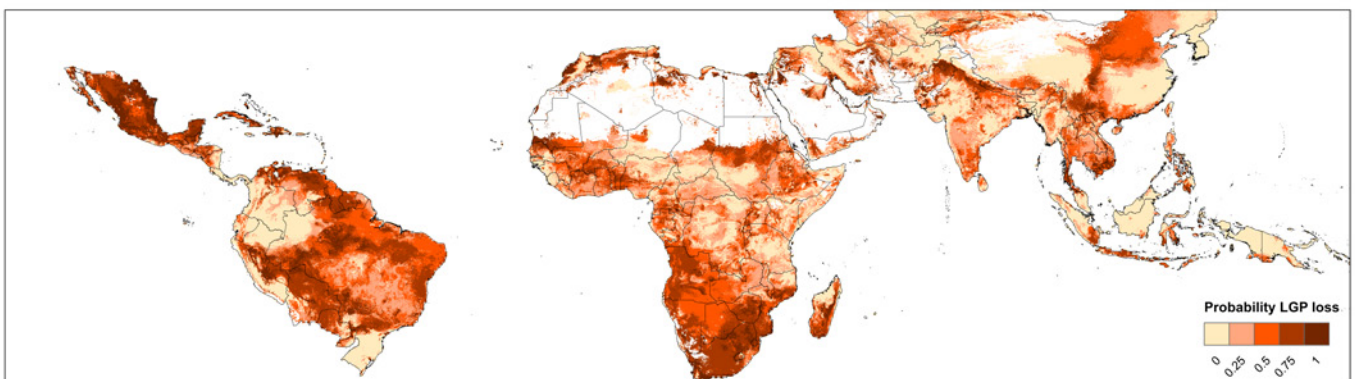

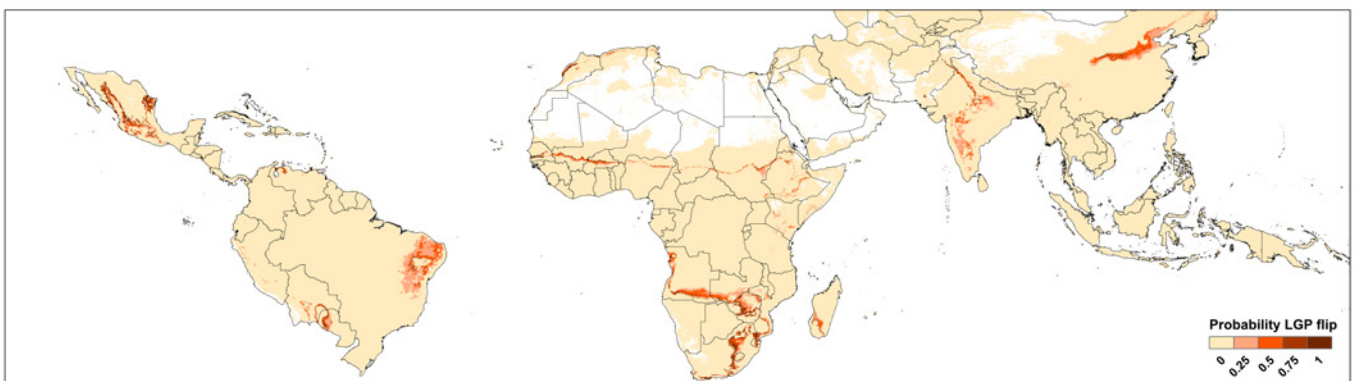***Map A.1.*** *Probability flip Tmax primary growing season from < 30°C to > 30°C.*
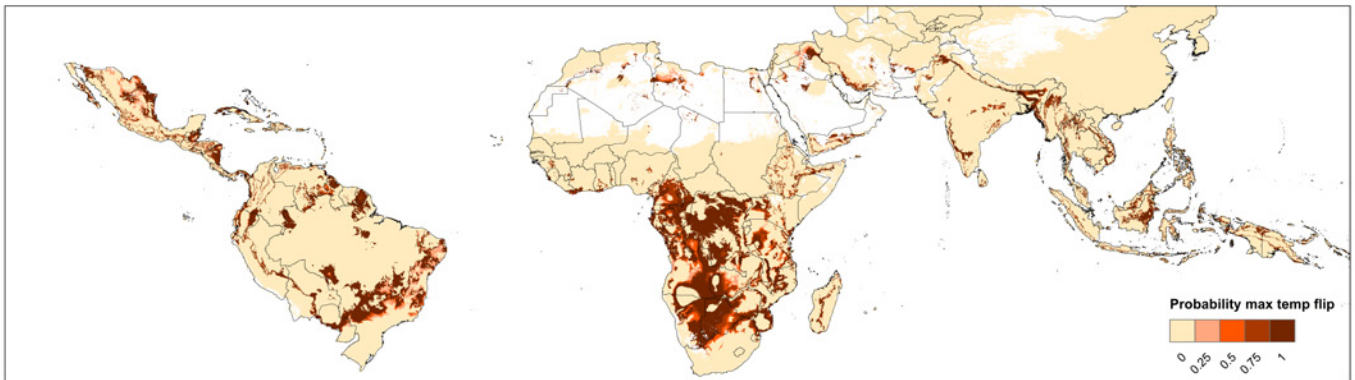
Map A.2. *Probability Tmax flips < 30°C to > 30°C.*
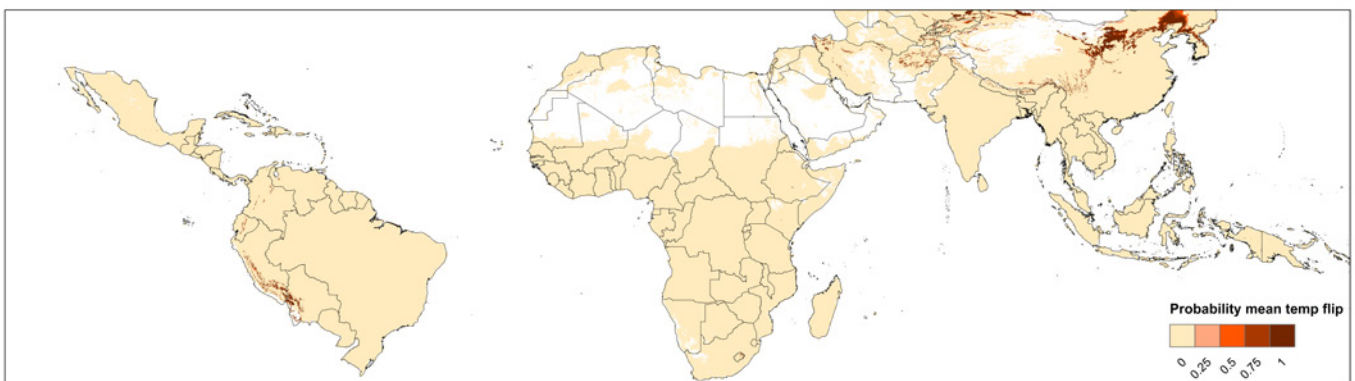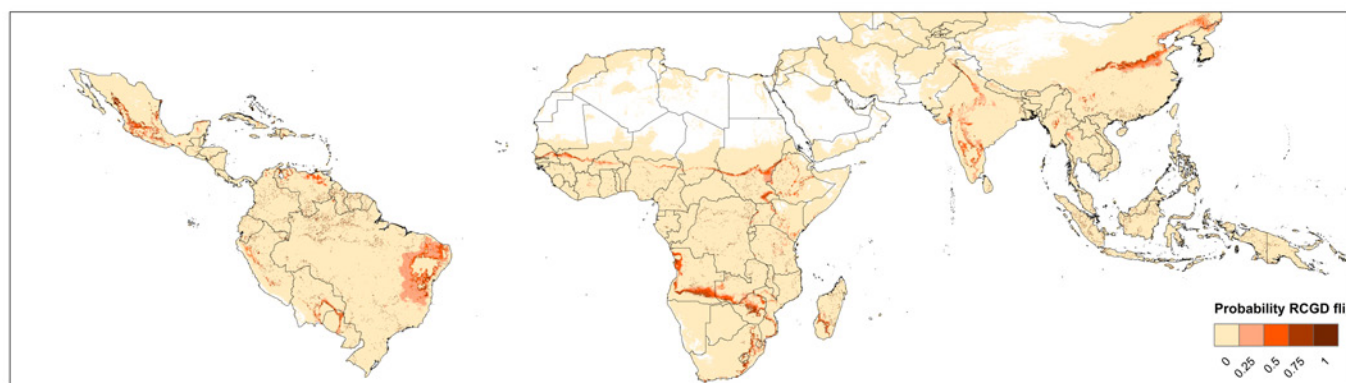

Map A.3. *Probability Tmean flips from < 8°C to > 8°C.*

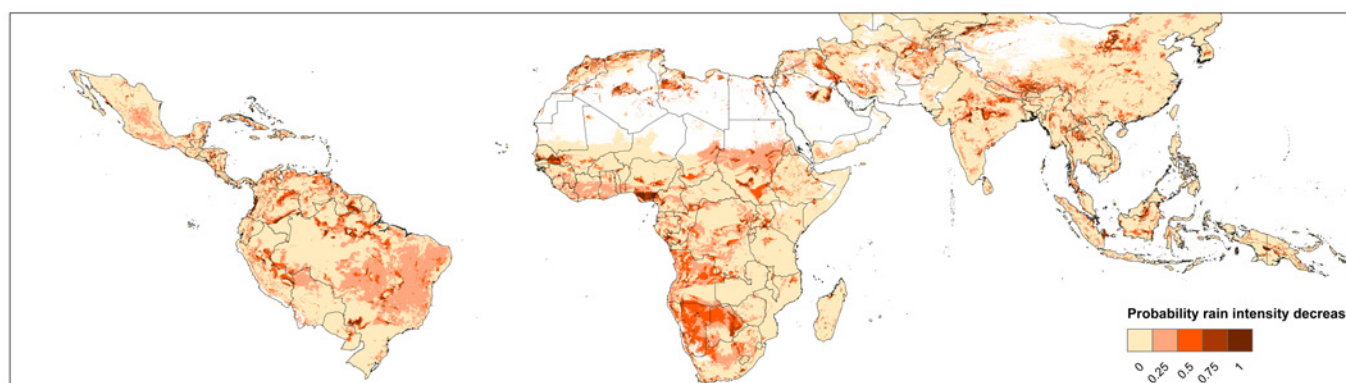**Map A.4.** *Probability of LGP decrease > 5%.*

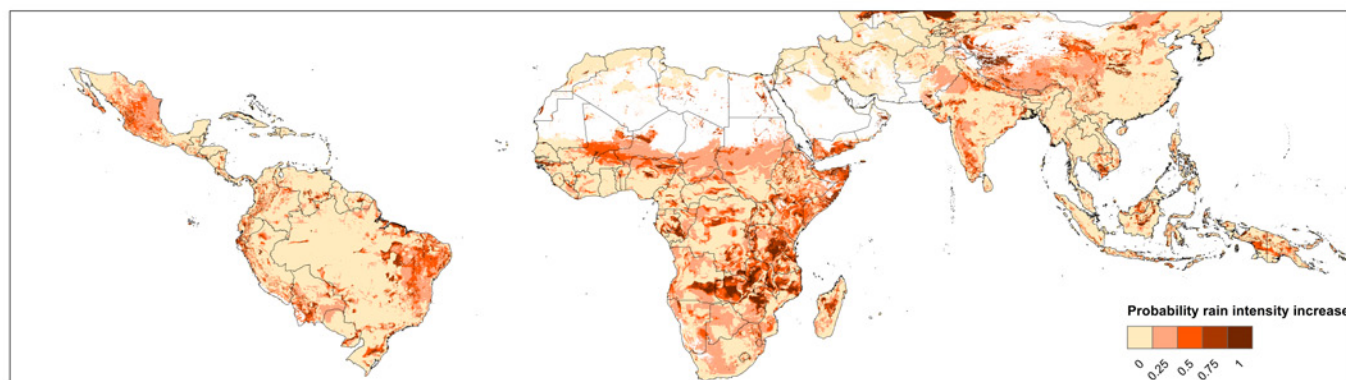**Map A.5.** *Probability of LGP flip from >120 days to < 120 days.*

Map A.6. *Probability of RCGD flip from > 90 days to < 90 days.*

Map A.7. *Probability rain per rainy day decreases.*

Map A.8. *Probability rain per rainy day increases.*

This report describes a study undertaken to identify areas that are food insecure and vulnerable to the impacts of future climate change, across the priority regions for the CGIAR centres.   The goal was to identify 'hotspot' locations where climate change impacts are projected to become increasingly severe by 2050 and food insecurity is currently a concern, using a range of indicators. The project was intended to help CCAFS by giving input to the selection of new target regions (i.e. multi-country) ex ante, and also as an ex post check of the three target regions chosen at the start of the project: East Africa, West Africa and the Indo-Gangetic Plains (IGP). In addition, the project is the start of a process that will link to regional scenarios and regional and local quantification work. Using maps as aids in the visualization of the possible impacts of climate change across the tropics and within regions will be important. This project also demonstrates the multiple indicators of food security that can be mapped and will interact with climate change. Finally, the project contributes to CCAFS work by including methods for mapping both food insecurity and the impacts of climate change on agriculture and food security, and giving guidance on interpreting results, particularly overlap, or lack of it, between the two categories of hotspots.

The study first mapped variables that indicate the different aspects of food security (availability, access and utilization), and then mapped thresholds of climate change exposure important for agricultural systems. Vulnerability was assessed using a domain approach based upon the IPCC framework of vulnerability as a function of exposure, sensitivity and coping capacity. Nine domains were identified, and areas of the tropics were classified for each domain by high or low exposure, high or low sensitivity, and high or low coping capacity.

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