Extreme Climate Events and Migration: An Agent-Based Modelling Approach

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Abstract

This is a study of migration responses to extreme climate events. Based on data from Nang Rong, Thailand, we construct an agent-based model that incorporates dynamic linkages between demographic behaviors, such as migration, marriage, and births, and agriculture and land use, which depend on weather patterns and other variables such as slope, soil type and elevation. With this model, we simulate patterns of out- and return migration in the face of 'normal' weather patterns, a seven year flood, and a seven year drought in a rice economy. Agent based modeling is a relatively new but increasingly popular methodology in the social sciences that allows the analyst to computationally simulate specific macro-level events in isolation of other macro-level events, and as such it creates the opportunity to circumvent many of the classic methodological problems in with the study of climate change and migration.

Introduction

This article is a study of migration responses to extreme climate events. With increasing concern about global climate change and variability in the meteorological sciences, social science studies on migration responses to such events have burgeoned in the past decade (cites). These studies describe strong theoretical connections between climate and migration, especially in rural areas where subsistence agriculture is fragile and depends on consistent and favorable weather patterns. In numerous ways these theories build on the classic demographic theory of multi-phasic change and response (Davis 1963) which postulated that population pressure and resource strain lead to multiple behavioral responses including migration.

Despite the conceptual and theoretical importance of this topic, it has been plagued by methodological challenges that make it difficult to attribute changes in migration patterns to changes in climate and weather variability. The most pertinent concern is that there are numerous and dynamic linkages between macro-level context and micro-level behavior. For instance, it has long been argued that social networks are an important factor leading individuals to out-migrate from rural areas (Tilly and Brown 1967), but Entwisle et al. (2007) show that communication flows in such networks are disrupted by high-levels of out-migration. Following this logic, climate change may increase migration in the short term - by increasing the relative returns to urban wages (Taylor YEAR) or reducing a household's dependence on agriculture as a livelihood strategy (Lucas and Stark YEAR) - but social network processes may interact with out-migration levels to either amplify or reduce these effects. On one hand, larger numbers of out-migrants in a social network may lead to increased knowledge of jobs and housing options in the destination - which can be expected to increase out-migration (Massey et al. 1993) - but, on the other hand, high levels of out-migration may cause the traditional channels of communication in rural areas to break down - reducing the likelihood that such information can be transferred (Entwisle 2007).

Migration is a common strategy around the world, and periods of increased and decreased migration have been documented in most countries (CITES). Thus, changes in migration cannot automatically be attributed to weather or climate. Climate and weather are also, and have always been, variable. Humans have long ago developed adaptive responses to the annual floods in the Mekong River Delta, drought conditions in the Sahel, and monsoonal variability across South and Southeast Asia (CITES). As a result, it is difficult to identify new types of changes to the climate and new adaptive responses in the context of continual adaptation to annually variable weather. Finally, in addition to climate change, other macro-level events happen all the time anyway. Regular occurrence of political or policy changes, population growth, and economic changes, at the same time as climate change makes it analytically problematic to isolate the effect of climate on migration, independent of other factors. Indeed, some of the most common studies of the climate-migration relationship are those that exploit the exogenous nature of climate events (e.g., reduced rainfall) to study how endogenous processes like social networks (CITES), resource dependence (CITES), or assets and income (CITES) affect migration.

In contrast to other work which examines the climate-migration relationship descriptively or which attempts to use climatic variation as an unbiased estimator of other social processes which influence migration, in this article we explicitly model the dynamic and interactive pathways through which climate-migration relationship may operate. We do this through the use of agent based models. Generally, an agent-based model is a programmed system of equations which reflect empirical understandings of the micro-level mechanisms underlying a macro-level relationship. This system is then typically used to explore the macro-level implications of stochastic, empirical or counter-factual heterogeneity in the micro-level processes. Owing to interactions and feedback loops in the conceptualized processes, these forms of heterogeneity may produce dynamic, cyclical, or counter-intuitive results that could not be modeled with standard regression-style analysis. Agent based modeling (ABM) is a relatively new but increasingly popular methodology in the social sciences that allows the analyst to computationally simulate specific macro-level events in isolation of other macro-level events (cf. Epstein [2006] or Macy and Willer [2002] for an overview), and as such creates the opportunity to circumvent many of the classic methodological problems in the study of climate change and migration.

The ABM upon which this article is based is situated in Nang Rong, Thailand. The ABM incorporates linkages between demographic behaviors, such as migration, marriage, and births, and agriculture and land use, which depend on weather patterns and other variables such as slope, soil type and elevation. With this model, we simulate several climate scenarios, including 'normal' weather patterns, a seven year flood, and a seven year drought, and analyze the impact of these scenarios on out- and return migration. Because this is a computational simulation approach, we are able to simulate weather events in the complete absence of other macro-level changes. This approach also allows for the examination of trajectories of migration over 50 years. Thus we can compare 'normal' patterns of change in migration patterns, with patterns of change that occur in the face of extreme climate events.

Setting

This study is based in Nang Rong District, Thailand. For several decades, this area has served as a study site and laboratory to explore interactions among people, place, and environment through theories, data, and methods emanating from the social, natural, and spatial sciences (Entwisle, Walsh, Rindfuss, and Chamratrithirong 1998; Walsh, Rindfuss, Prasartkul, Entwisle, and Chamratrithirong 2005). As a result, there is a significant amount of literature about these subjects in this particular area. Along with being generally comparable to other rural agricultural areas in Thailand and much of Asia, the ability to draw on the existing literature and survey data makes this study site an ideal location to implement a theoretically motivated and data informed agent-based model.

Nang Rong district occupies approximately 1300 km^2 in Northeast Thailand, as shown in Figure 1. As a generally rural district, the economy has historically been based on subsistence agriculture of rice, kitchen vegetable gardens, and some livestock. In the last few decades, farmers in Nang Rong have become increasingly engaged in market agriculture. Although most farmers grow rice, both a subsistence and cash crop in this setting, some also grow upland cash crops such as cassava, sugar cane, eucalyptus, rubber, and fruit trees.

[Figure 1 about here.]

Villages most often consist of clusters of dwelling units surrounded by agricultural lands. They are commonly located on small hills or rises proximate to low lying lands suitable for paddy rice cultivation (Riethmuller, Scholz, Sirisambhand, and Spaeth 1984; Phongphit and Hewison 2001). These patterns of residential settlement mean that most social affiliation and communication are locally based within the village (Entwisle et al. 1996). Figure 2 shows the location of villages in Nang Rong relative to inundation patterns revealed in a rare July 2000 satellite image from the rainy season. Notice that except for villages located in the upland southwest, which was settled most recently in response to an increase in world demand for cassava (a crop that can be grown in upland settings), villages line up along the edges of the inundated area.

[Figure 2 about here.]

The environmental setting is one of marginality. Soil fertility is relatively low, drainage is poor, and generally speaking, there is a limited natural resource base. The climate is monsoonal, with rains arriving in the late spring to early summer. The rice harvest occurs in December, followed by a long dry season with few agricultural activities. Precipitation, however, is unpredictable and changing over time. As shown in Figure 3, which plots rainfall patterns in Nang Rong over the past 50 years, there is a clear downward trend in rainfall, but also increased variance. For example, during the 1990s, there were two years of extreme wetness (1993, 1999) and two years of extreme drought (1992, 1997).

[Figure 3 about here.]

Migration, both permanent and temporary (including seasonal), is common in Nang Rong (Fuller, Lightfoot, and Kamnuansilpa 1985; Fuller, Kamnuansilpa, and Lightfoot 1990; Guest 1996; Korinek, Entwisle, and Jampaklay 2005). Nang Rong farmers must deal with shocks originating in the national and international economy as well as those environmental in nature.

Analytical Strategy

The Agent-Based Modeling Approach

Agent-based modeling, the core analytical approach for this study, is a promising technique for the investigation of the short- and long-term, multi-dimensional, micro- and macro-level consequences of climate change. Broadly, ABMs are simulations of a population of autonomous heterogeneous agents that are allowed to interact with each other and their environment according to simple prescribed rules. The dynamic actions of agents at the micro-level and response to the behaviors of other agents and characteristics of their environment result in regularities or emergent patterns at the macro-level. As a computational technique, ABMs can also be used to examine outcomes of different experimental scenarios of extreme weather events, making them particularly valuable for research on the short- and long-term consequences of climate change when it is inappropriate, if not impossible, to wait for these consequences to play out over time.

ABMs also allow for the direct incorporation of feedbacks which are fundamental to the dynamism of human and ecological systems. These feedbacks are of two types. One involves endogenous relations among key variables: for example, the risk of migration depends on household assets, which in turn depend on prior productivity of specific plots of land; use of specific plots depends on household assets, which in turn depend on prior migration and remittance behavior. Interconnections among migration, land use, and household assets thus operate across individual household members, households as collective units, kin networks and villages, and the geographic site and situation of specific land plots and village territories.

The other type of feedback involves interaction among agents, or, the influences that neighbors have upon each other. For example, research consistently shows that migration is cumulative (Massey et al. 1993; Massey 1990; Massey et al. 1987), such that the behavior of one migrant helps to define the context of possibilities for subsequent potential migrants. In studies using statistical models, this feature of migration is typically captured through measures of the number of family members or the percent of community residents who have migrated (Massey and Espinosa 1997; Massey 1991). Alternately, the ABM approach incorporates these influences by including changing measures of the number of migrants and social network ties at the household and village level, as well as incorporating dynamic measures of migration, return migration, and remittance behavior into the evolving village network structure. In this way, ABMs provide the ability to analyze the dynamics of an interconnected system over time, making it possible to find emergent and unexpected patterns in trajectories that would not be possible with a statistical regression approach.

Overview of the Computational Model

In this section we provide a brief overview of the ABM upon which this study is based. Further details of the model are available in Entwisle et al. (2008).

Our agent-based simulation includes several multiple types of inter-related units, or agents: individuals, land parcels, households, social networks, and communities. Households are a point of integration for the model: individuals form households, which are embedded in social networks and communities. Land parcels are owned, managed or used by households. Villages are composed of households, and social networks consist of ties among those households. The model assumes that households have decision-making authority for the management of land parcels.

Each element of the model has attributes and can experience demographic, social, economic, and/or biophysical processes. Individuals are characterized by age, sex, marital status and years of education. They experience the possibility of mortality, out-migration, return migration, marriage, establishing a new residence locally, and, for women, giving birth. When not residing in the community they can remit to the origin household, influencing that household's assets. The ABM computes, that is, simulates, each of these processes on an annual basis, updating and taking into account attributes of the individual as well as the individual's household, social network ties to other individuals and households, and community.

Land parcels also have attributes, such as size, distance from the village, flooding potential and topographic settings, land use type, and soil suitability for various agricultural uses. Depending on these attributes, household resources, and environmental factors such as the timing and amount of rainfall, the household makes a choice about how to use the land parcel, (for rice, sugar, or cassava cultivation) and experiences some level of productivity which is again based on the timing and amount of rain.

Migration in the ABM

The processes just described are estimated within the ABM annually using a set of stochastic operations or 'rules'. These rules are described elsewhere (Entwisle et al. 2008), but the focus of this article on migration requires that we address the migration 'rules' with some detail here.

The rules for out- and return migration use a regression approach and derives from analysis of Nang Rong survey data as well as relevant substantive and theoretical literature. Regression models were estimated to predict out- and return migration based on characteristics of individuals, their households, social networks, and communities. The coefficients from these regression models were then used in the agent-based simulation to determine who migrates or returns in a given year (cf. Entwisle et al. 2011).

Climate Scenarios in the ABM

To examine the role of climate change on migration, we simulate three climate scenarios in the ABM. We label these scenarios normal, seven-year drought, and seven-year flood. They were created based on data of actual weather patterns from 1900-2000. For each year during this century, the amount of rain and the timing of the start of the monsoon were recorded. The average amount of rain during this period is defined as 'normal'; two standard deviations above the mean is defined as 'wet' and two standard deviations below the mean are defined as 'dry'. Similarly, the average start date is called 'normal', and two standard deviations above and below the average start date are considered 'late' and 'early'. Not surprisingly, years during which the monsoon was late also tended to be dry and years when the monsoon was early were generally also wet.

The normal climate scenario is then created by making every year start on the normal date and experience the normal amount of rain for the full 50 years of the simulation. The seven-year drought scenario is comprised of dry and late years from year 10 through year 17. Every year before year 10 and after year 17 experiences normal amounts of rain starting at the normal time. The seven-year flood scenario includes wet and early years from year 10 through 17, with every other year experiencing normal timing and normal amounts of rain.

Results

In the models which follow, we test how average levels of village migration differ between these three scenarios, and whether such differences exceed those that might be found at random within a single climate scenario owing to stochastic fluctuations in the processes we explore. We also examine heterogeneity in migration response and whether some groups, especially the most vulnerable with the fewest assets and least productive lands, are more affected than others. Finally, our model allows us to directly examine the mechanisms through which climate is influencing migration, for instance from crop-yields to assets to migration, and whether households are pursuing any adaptive strategies that may dampen the influence of climatic fluctuations on migration.

We are currently analyzing the outputs of our simulations and here present only selected results for this extended abstract.

The central mechanism through which we anticipate climate change impacts on migration is crop yields and their effects on household assets. Our model is constructed in such a way that rainfall influences crop yield, though this effect may be moderated by geographic heterogeneity in a households' plot locations - e.g., whether their plots are situated on land that is dry or wet in normal weather conditions, if their plots are on steep slopes or in soils more or less likely to retain water. Another level of complexity is that yields of different crop types may exhibit differential responses to droughts and floods - e.g., rice needs more water than cassava.

Figures 4-6 show the impacts of droughts and floods in our three climate models. Each presents the annual trends in total village yield in rice, sugar cane, and cassava, respectively, averaged over the 100 simulated runs. The three climate scenarios are indicated by the line markings - the solid line represents the normal scenario, the dotted line the flood scenario and the dashed line the drought scenario. Recall that the simulated flood and drought occur in years 10-17.

As can be seen in figure 4, there is a nearly immediate impact of dryer or wetter conditions on rice yields in the village. Interestingly, droughts appear to have more of an influence than floods. This sentiment was mentioned by Nang Rong rice farmers in qualitative fieldwork conducted in 2010 (Entwisle et al. unpublished results), but it was not programmed into the model. It is a product of the geographic locations of plots and the modeled outputs of DSSAT, a widely accepted agricultural model of yield outputs which we employed (CITE). As the climate returns to a period of normalcy after year 17, the yields return to normal and are not differentiated by climate scenario.

Figures 5 and 6 show the impacts of droughts and floods on the two upland crops we model, sugar cane and cassava. In contrast to rice, the effects of the climate scenarios here are more delayed and, for sugar, they work in the opposite direction. A very interesting and important feature of figures 5 and 6 is that the total yields in the flood and drought conditions do not return to the normal levels after the flood or drought ends in year 17. Sugar cane yield totals remain higher in both of these treatment scenarios than they do in the normal scenario, while cassava yields remain lower. This appears counterintuitive, but it is actually an interesting dynamic of the models. It can be explained by people switching from cassava into sugar cane during the treatment years and remaining in the new crop in later years. Another counterintuitve feature of these models is that the opposite conditions - more or less rain - produce effects in the same positive direction for sugar cane, with floods being more beneficial. A likely explanation for this is that those who were growing sugar were doing so on land that was too dry and they benefitted from increased wetness. The increased yield from drought conditions is likely the effect of people on land that was only marginally acceptable for rice farming switching to growing sugar. That the sugar yields for flood conditions peak rapidly during the flood period then fall sharply in year 17 while the sugar yields for drought conditions only slowly increase is consistent with this explanation.

Figure 7 shows how important crop yields are for these rural farmers by looking at trends in average household assets, averaged across the 100 simulations we conducted. The flood and drought have lasting influences on household assets, but the drought - as our qualitative participants told us - is more damaging to assets in the long run. Indeed, the seven years of drought exhibit no growth on average in our village while the seven years of flood only slow growth.

We expect that such changes in assets will impact migration. In our migration model (cf. Entwisle et al. 2011), the risk of out-migration is negatively associated with household assets. However, there are numerous other pathways through which this effect may be mitigated. For instance, does the switching from cassava to sugar cane farming somehow offset the hypothesized influences on migration? Perhaps the benefits seen in sugar yields in these conditions cause some households, such as those on more marginal lands who are the most likely to migrate, to do better while leading the better-off households growing rice to do worse. Such countervailing effects, depending on the distribution of households with individuals at risk of migration, may lead to no net change. Further, there is also the potential that social network influences are operating as having a kinship tie to a wealthy household is a factor influencing migration. Another potential network influence is an (intentionally modeled) endogeneity in the network model. Those connected to migrants are more likely to migrate, but migrants send remittances which increases a households' chances of being able to use fertilizer to offset the decline in crop production. It is entirely possible that some households experience increase risk of migration from lower yields but that, once one individual migrates, other members are then at lower risk because they can pursue a livelihood strategy (fertilizer application) that increases yields. These and other questions are the focus of the remainder of our paper.

At present, our results point to less than anticipated influences of climatic variation on migration rates. Although a potentially interesting result, we hesitate to make much of this currently as we have not fully interrogated all potential mechanisms. As we move the paper along, we will examine whether this lack of influence owes to adaptation and compensation in response to climate change (e.g., households farming different crops), whether climatic variation is altering the composition of the migration stream but not its total size (e.g., more poorer households migrating but fewer from the middle of the assets distribution), and other hypotheses that might produce this effect.

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Phongphit and Hewison 2001

Riethmuller, Scholz, Sirisambhand, and Spaeth 1984

Walsh, Rindfuss, Prasartkul, Entwisle, and Chamratrithirong 2005

FIGURES

Figure 1. Map of Nang Rong District, Thailand

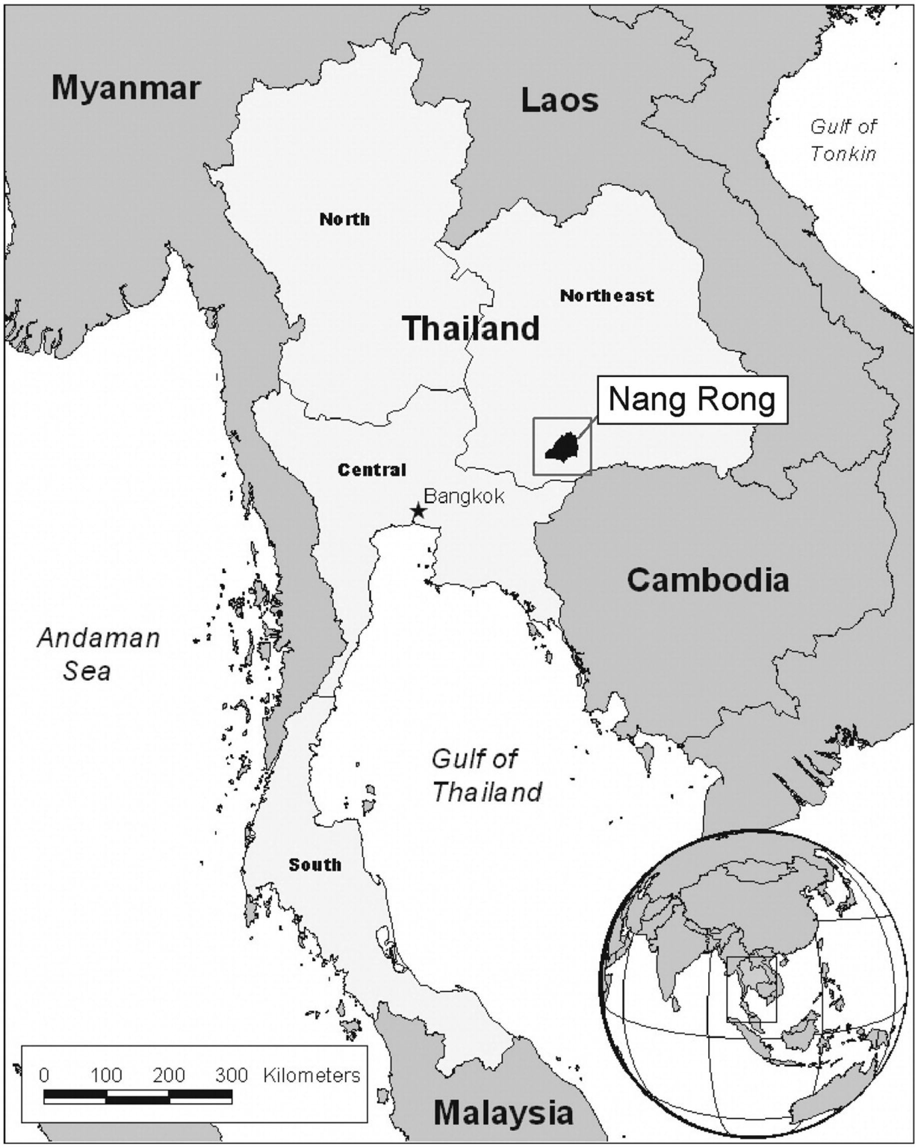

Figure 2. Map of Nang Rong villages and inundated areas: village centroid to parcel links.

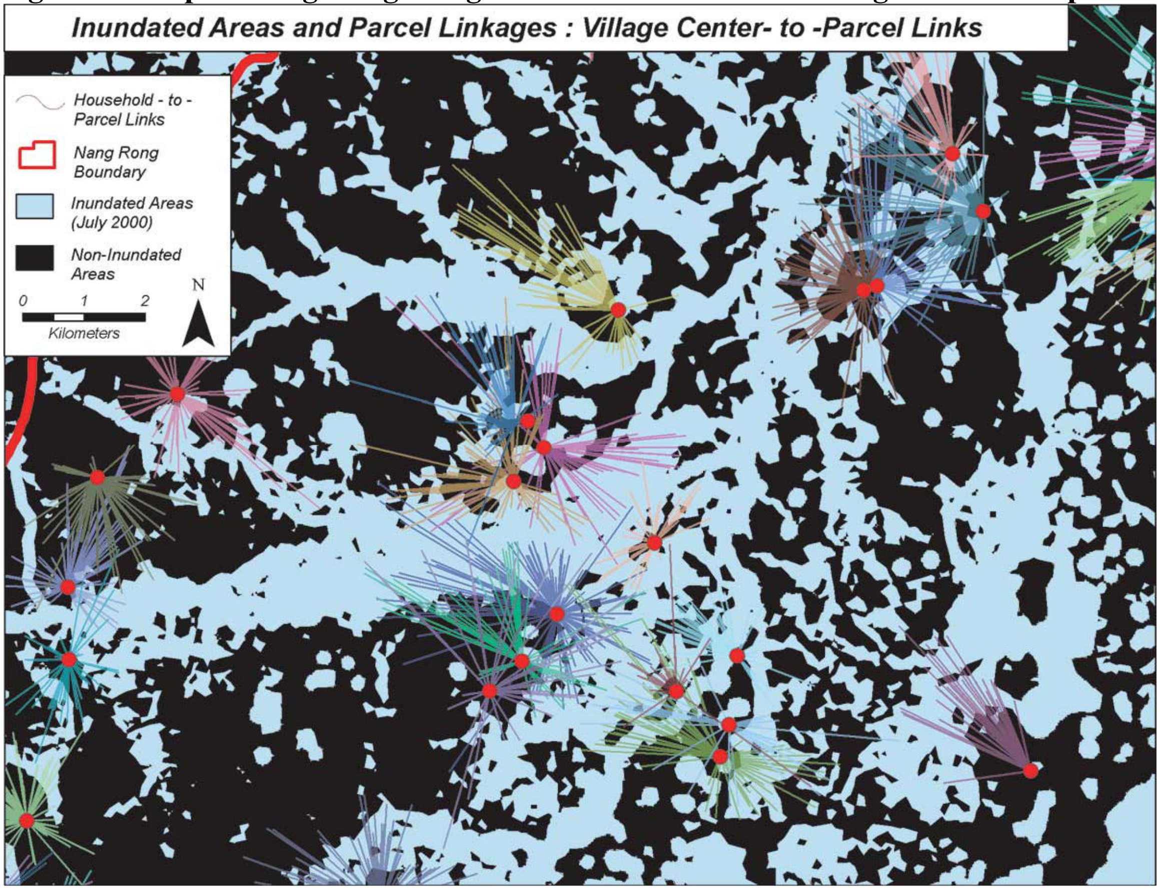

Figure 3. Annual precipitation in Nang Rong, Thailand, 1950-1999 (0.05 degree cell).

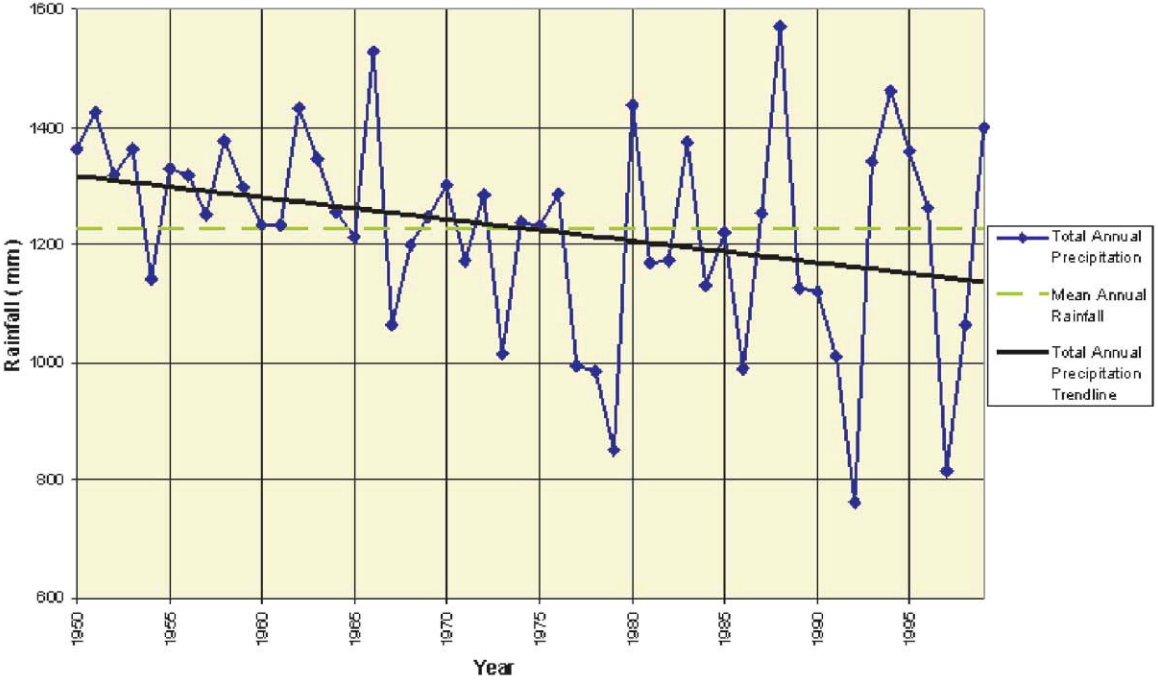

Figure 4. Average rice yields for three climate scenarios.

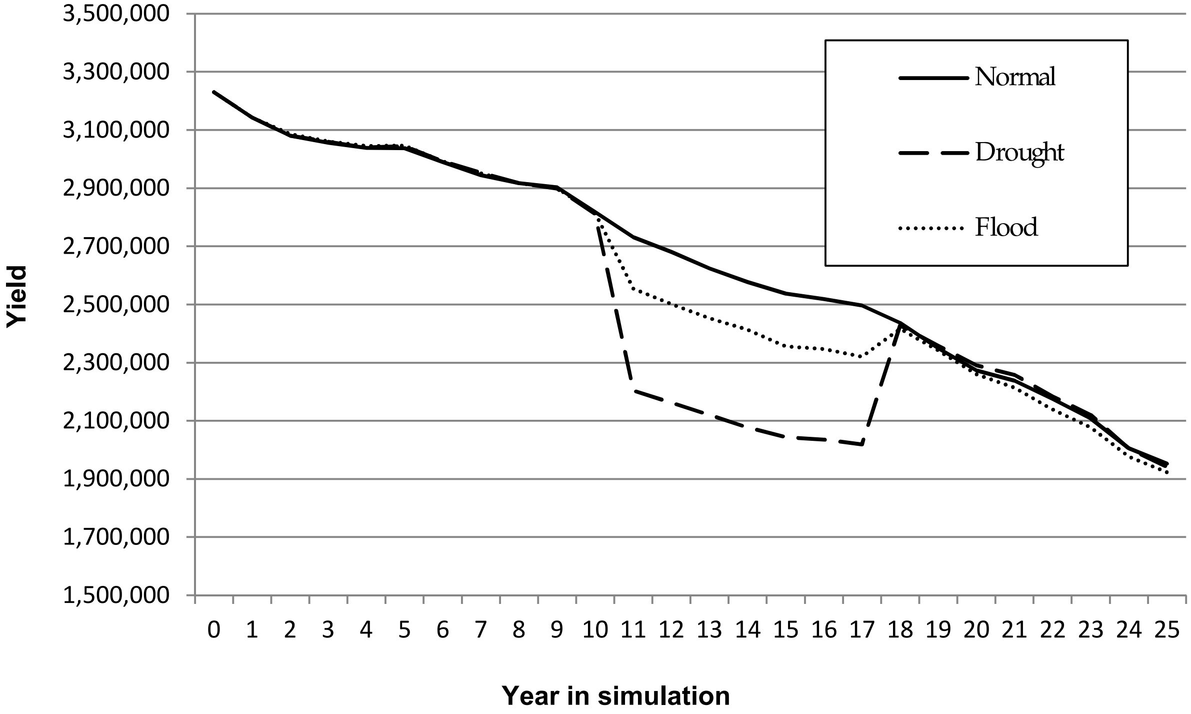

Figure 5. Average sugar cane yields for three climate scenarios.

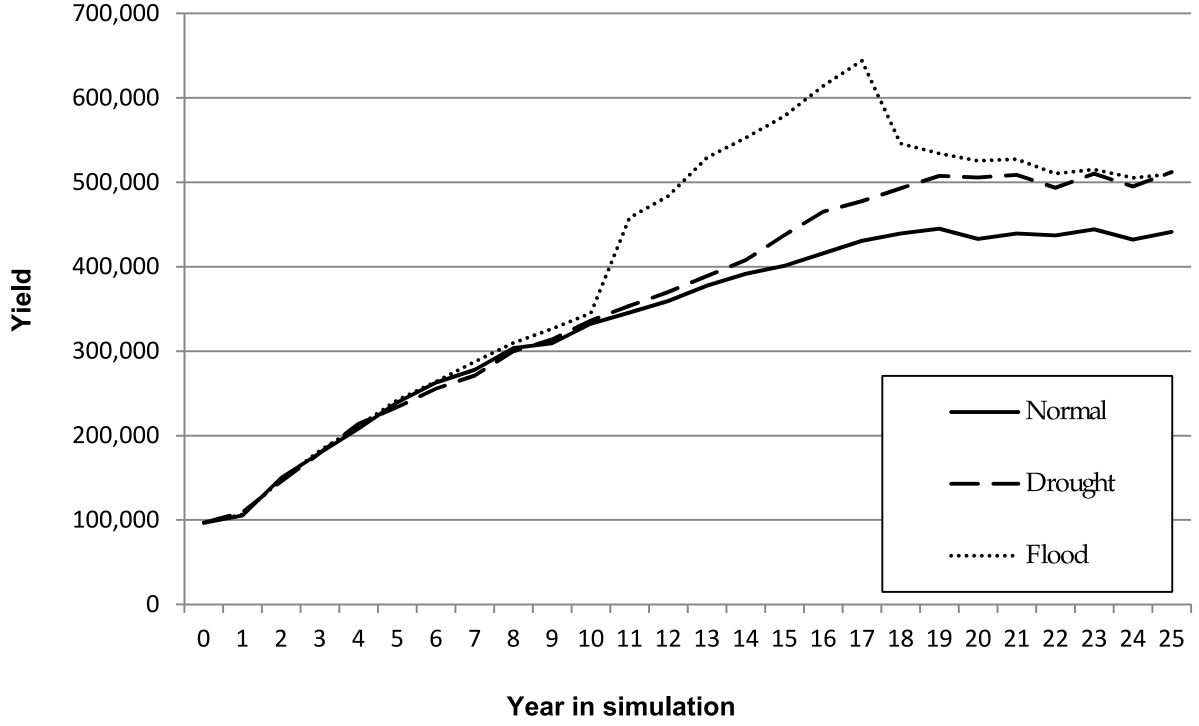

Figure 6. Average cassava yields for three climate scenarios.

Figure 7. Average assets for three climate scenarios.