Vulnerability of the Sahelian Rural Populations to Climate Variability: Mathematical Modeling of the Socio Economic Dynamic

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Outline

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1. Introduction
   - Context
   - Research objectives
2. Outcomes: modeling
   - First model: one patch (village)
   - Second model: two patches connected by migration
3. Conclusion and perspectives

Fondation 2iE

1. The Sahelian rural population is considered one of the most vulnerable on earth (Martineu & Tissot, 1993; Lebel & Amani 1999; New et *al.* 2000).

Reasons

- High dependence on natural resources,
- Economy based on the primary sector with a high population,
- Economic poverty (average GNP= 360 $ US inhbt/year)...

Consequences

- The reduction of agricultural production,
- The deteriorating of food security and livelihood...

Coping strategies

Migration, off-farm activities, livestock breeding and irrigation

2. These options are sufficient for the sahelian population to escape the vicious circle of poverty and to reduce their vulnerability?

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2. To develop a deterministic model of compartimental system in order to study the present and future socioeconomic vulnerability to climate variability,
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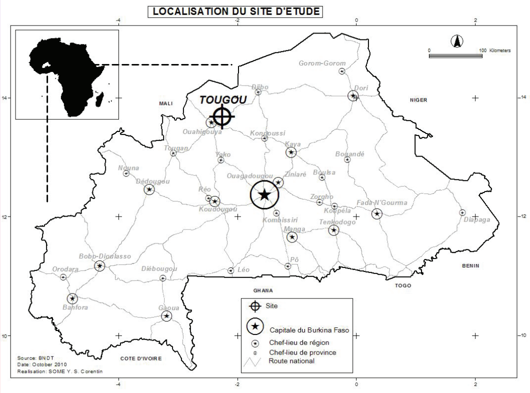
Method

Sampling: Household survey

Burkina Faso (Tougou): 2004, 2006, 2008 & 2010.



Method

Compartmental analysis

Compartmental analysis is a mathematical modeling technique to come to differential systems : ODE and PDE. Ordinary Differential Equation used in our case.

To do this we must:

- define the number and the quality of compartments.
- quantify the exchanges between the different compartments.

Index vulnerability

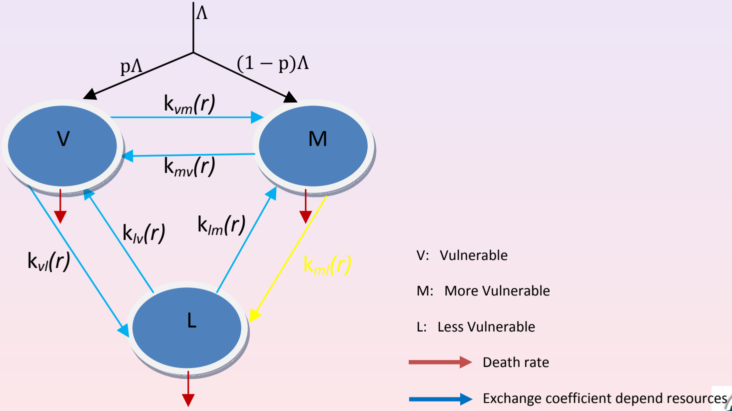
Definition (index vulnerability)

We calculate an index of food vulnerability developed by CILSS. The index is called the Virtual Rate of Satisfaction of Grain Needs (Garavani 1997; CILSS 2001).

It balances production and consumption of basic grains such as millet, sorghum, maize, and rice. It then estimates the cash income from activities such as sales of beans, peanuts, small animals and irrigation.

Conceptual model

Index vulnerability: *Vulnerable* (between 90% and 110%); *Less vulnerable* (more than 110%); *More vulnerable* (less than 90%)



(a) Vulnerability compartment (b) Legend

Hypothesis

Assumptions

- $k_{ij}(R) = a_{ij}R(t)$ is the exchange coefficient from the hight vulnerability to the low vulnerability and $k_{ij}(R) = \frac{a_{ij}}{R(t)+b_{ij}}$ is the exchange coefficient from the low vulnerability to the hight vulnerability,
- $b_l = b_m = b_v = b$ and $f_l(N) = f_m(N) = f_v(N) = f(N)$,
- $f(N) = \mu_h + \mu_{2h}N$ where μ_h is the density independent part of the death rate and μ_{2h} is the density dependent part of the death rate,
- A new born takes the degree of vulnerability of the household,
- No vulnerability-induced death rate,
- No passage from *More vulnerable* class to *Less vulnerable* class;
- Climate is a unique the covariate shock no idiosyncracy chock.

Model equation: Vulnerability dynamics of group

Model equation

$$\frac{dV}{dt} = p\Lambda + (b_v - f_v(N))V - (k_{vl}(r) + k_{vm}(r))V + k_{mv}(r)M + k_{lv}(r)L, \quad (1a)$$

$$\frac{dM}{dt} = p^{'}\Lambda + (b_m - f_m(N))M + k_{lm}(r)L - (k_{mv}(r) + k_{ml}(r))M + k_{vm}(r) \quad (1b)$$

$$\frac{dL}{dt} = (b_l - f_l(N))L + k_{ml}(r)M - (k_{lm}(r) + k_{lv}(r))L + k_{vl}(r)V,. \quad (1c)$$

- b_i and $f_i(N)$ are respectively the birth rate and the death rate of group i where $i \in \{V, L, M\}$;
- Λ: immigration rate;
- $p + p^{'} = 1$, with $(p, p^{'}) \in [0, 1]^2$.

Model equation: dynamics of resources

$$\frac{dr}{dt} = -\pi(N) = -\alpha N(t) r \quad (2a)$$

$$r(t_i^+) = r_p(t_i) + r(t_i^-). \quad (2b)$$

- $r(t_i^+)$ is the available resources in year t_i;
- $r_p(t_i)$ is the produced resources year in t_i;
- $r(t_i^-)$ is the remaining stock year in t_i.

$$r_p(t_i) = a\bar{m}_{i-1}^2 + b = a\left(\sum_{i=0}^{8} \rho_i sin(\omega_i t + \phi_i)\right)^2 + b,$$

where $\bar{m}_{i-1}$ is the rainfall of previous year and ρ_i,ω_i et ϕ_i are the coefficient determined by interpolation (non linear regression) with $R^2 \geq 0.7$.

Cost functional :Least square

Discretization of $\frac{dv}{dt} = \frac{v(t_{i+1})-v(t_i)}{t_{i+1}-t_i}$, $\frac{dm}{dt} = \frac{m(t_{i+1})-m(t_i)}{t_{i+1}-t_i}$ & $\frac{dl}{dt} = \frac{l(t_{i+1})-l(t_i)}{t_{i+1}-t_i}$

$$J_v = \sum_{i=0}^{n}\Big(v_i - \frac{p\Lambda}{N(t_i)} + \frac{\Lambda}{N(t_i)}v(t_i) + (a_{vl}r(t_i) - \frac{a_{vm}}{r(t_i)+b_{vm}})v(t_i)$$

$$- a_{mv}r(t_i)m(t_i) - \frac{a_{lv}}{r(t_i)+b_{lv}}l(t_i)\Big)^2 ; J_m = \sum_{i=0}^{n}\Big(m_i - \frac{(1-p)\Lambda}{N(t_i)}$$

$$+ \frac{\Lambda}{N(t_i)}m(t_i) - \frac{a_{lm}}{r(t_i)+b_{lm}}l(t_i) + a_{mv}r(t_i)m(t_i)$$

$$- \frac{a_{vm}}{r(t_i)+b_{vm}}v(t_i)\Big)^2 ; J_l = \sum_{i=0}^{n}\Big(l_i + \frac{\Lambda}{N(t_i)}l(t_i) + (\frac{a_{lm}}{r(t_i)+b_{lm}}$$

$$- \frac{a_{lv}}{r(t_i)+b_{lv}})l(t_i) - a_{vl}r(t_i)v(t_i)\Big)^2$$

Parameter identification: Maple

Parameters value

$$J = \min\Big\{ J(a_{mv}, a_{vl}, a_{lm}, a_{lv}, a_{vm}, b_{lv}, b_{lm}, b_{vm})$$

$$\mid (a_{mv}, a_{vl}, a_{lm}, a_{lv}, a_{vm}, b_{lv}, b_{lm}, b_{vm}) \in R^+ \Big\},$$

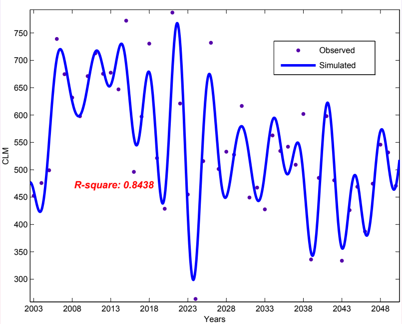
$J = 0.009$, $a_{lm} = 0.$, $a_{lv} = 26.771$, $a_{mv} = 0.001$, $a_{vl} = 0.006$,
$a_{vm} = 7.361$, $b_{lm} = 4.271$, $b_{lv} = 6.285$, $b_{vm} = 0.917$

Interpretation of socioeconomic dynamic vulnerability : $2004 - 2010$

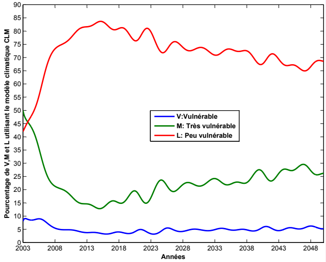
- No exchange between the *Less vulnerable* and the *More vulnerable* ($a_{lm} = 0$),
- Exchange between the *Vulnerable* group and over groups ($a_{vl}, a_{vm} \neq 0$).

Climate and dynamics of vulnerability of groups simulation with CLM

For simulation: 5 climatic model outputs of the projet Ensemble-EU used: *CLM, HC, RACMO, RCA & REMO*.



(c) model output CLM



(d) Dynamic of vulnerability of group with CLM

Outline

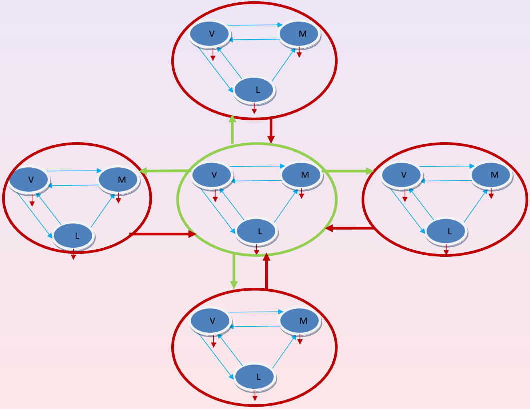
Method

Metapopulation model

A metapopulation model involves explicit movement of individuals between different localities. Metapopulation models type are spatially explicit and become very important in the study of spatiotemporal dynamics.

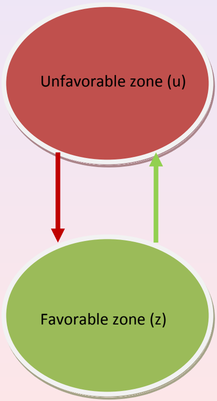
Third model: n patches

Impact of the migration on vulnerability of socioeconomic groups in the favorable zone.



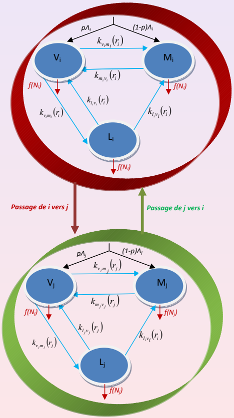
Second model: two patches without compartment

To take account the favorable zone and the unfavorable zone and the resources in the two patches.



Second model: two patches with compartment

To take account the favorable area and the unfavorable area and resources in the two patches. To subdivide each patch into compartment.



Model equation: n patches

Model equation for patch i, i=1,·, n

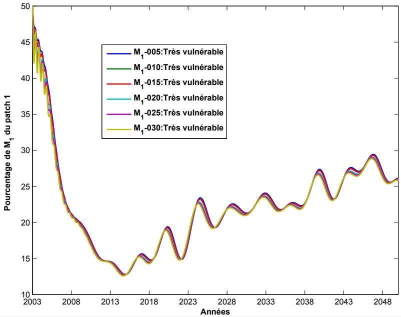
- $$\frac{dV_i}{dt} = p_i\Lambda_i + (b_i - f_i(N_i))V_i - (k_{v_i l_i}(r_i) + k_{v_i m_i}(r_i))V_i + k_{m_i v_i}(r_i)M_i + k_{l_i v_i}(r_i)L_i + \sum_{j=1}^{n} m_{ji}^{V} V_j - \sum_{j=1}^{n} m_{ij}^{V} V_i,$$
- $$\frac{dM_i}{dt} = p_i^{'}\Lambda_i + (b_i - f_i(N_i))M_i + k_{l_i m_i}(r_i)L_i - (k_{m_i v_i}(r_i) + k_{m_i l_i}(r_i))M_i + k_{v_i m_i}(r_i)V_i + \sum_{j=1}^{n} m_{ji}^{M} M_j - \sum_{j=1}^{n} m_{ij}^{M} M_i,$$
- $$\frac{dL_i}{dt} = (b_i - f_i(N_i))L_i + k_{m_i l_i}(r_i)M_i - (k_{l_i m_i}(r) + k_{l_i v_i}(r_i))L + k_{v_i l_i}(r_i)V_i + \sum_{j=1}^{n} m_{ji}^{L} L_j - \sum_{j=1}^{n} m_{ij}^{L} L_i,$$
- $$\frac{dR_i}{dt} = R_i^{p} - \alpha N_i R_i.$$

Parameters and Hypothesis

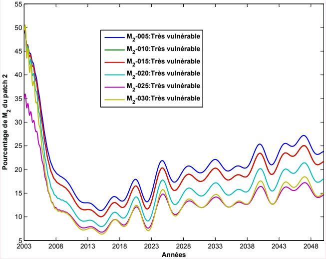
In the unfavorable patch and the favorable patch

- The same hypothesis,
- The same exchange between compartment,
- The same parameters identified,
- The same climatic model output (CLM),
- Households maintain their status of vulnerability during travel,
- The same resources with Tougou in the unfavorable patch and we increased for (5%, 10%, 15%, 20%, 25%, 30%) resources in the favorable patch.

Vulnerability dynamic of groups with CLM output for 2 patches

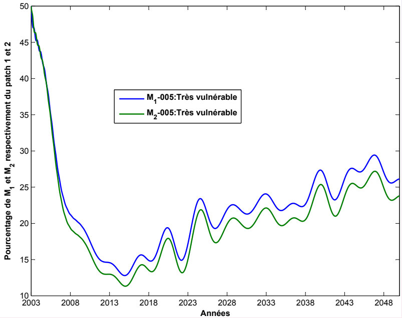


(e) Vulnerability dynamic of More vulnerable for unfavorable Patch 1 = Tougou

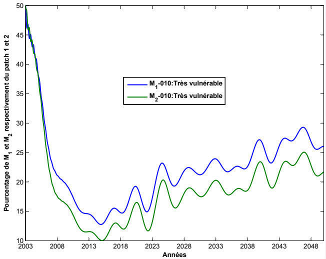


(f) Vulnerability dynamic of More vulnerable for favorable Patch 2

Simulation when we increase the resources in Patch 2



(g) More vulnerable in Patch 1 & 2 when increased resource in Patch 2 from 5%



(h) More vulnerable in Patch 1 & 2 when increased resource in Patch 2 from 10%

Conclusion and perspectives

Conclusion

- The model developed here permit to know the socioeconomic dynamic of vulnerability of Sahelian population to climate variability,
- In the future (until 2050) households will be less vulnerable with these 5 climatic model outputs (some case about 80%),
- These households are those that diversify their activities,
- Metapopulation model confirmed that migration movement (between unfavorable area and favorable area) increased because this strategies reduce population vulnerability (20%).

Perspectives

- The sensitivity analysis of the different parameters of our model,
- To take another covariate shock and the form of exchange,
- To take account the season rainfall effect,
- To introduce control for the different external chocks.

THANK YOU FOR YOUR ATTENTION