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A Mathematical Model for Assessment of Socio-Economic Impact of Climate Change on Agriculture Activities: Cases of the East of Morocco (Africa)

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Abstract

Objectives: The work aims to presents a novel application of mathematical modelling framework that is assesses Socio-economic impact of climate change on agriculture activities, taking into account the agricultural, socio-economic and hydrology systems. **Methods and Novelty**: An integrated model disaggregated by type of farms was developed for a pilot area named "Ait Ben Yacoub » located in the East of Morocco. This model integrates economic, agronomic hydraulic and social data. One Major contribution of this model is a detailed disaggregation by spatial units (hydrological units, cropping areas) and by farm sizes to assess the social impact of climate change on different types of farms. It's an optimization model with a nonlinear objective function and that was calibrated with the use of the positive mathematical programming method. **Findings:** The model results show the tremendous impact of climate change on farmers' incomes and on their living standards. It also shows that small farms of less than 2ha in area will be most vulnerable to climate change. **Applications:** The current work was designed to build a tool for analysis and support for decision making regarding policy on the allocation of the water resource, and also allowing a better reflection on the issue of water valorization in agricultural sector.

Keywords: Agriculture, Climate Change, Mathematical Model, Morocco, Socio-Economic Impact

1. Introduction

In Morocco, Water sector, characterized by spatial and temporal scarcity and irregularity, is currently facing major challenges such as an increasing demand, the scarcity of water resources and overexploitation of groundwater. Climate change makes the situation more difficult, especially due to the intensification of extreme events such as droughts and floods. The economy of the country which is very dependent on water resources, agriculture and its coastline should be strongly affected.[1] Agriculture sector still remains the most important sector of macro-economy. The sector accounts for only around 14.4% of GDP but employs 39 % of the Moroccan population. However, this sector consumes 85% of the mobilized water resources and it impacts negatively on quality of water resources through the leaching of nitrates and pesticides to groundwater.[2] In Morocco, Poverty is essentially a rural phenomenon. About 4 million people in the country live below the national poverty line, and 3 million of them

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are in rural areas and their incomes depend on agriculture.[3] Many of the rural ones have access to only a limited amount of non-irrigated arable land with a poor agricultural potential. The incidence and distribution of poverty vary considerably among regions regarding the quality and availability of natural resources. The Moroccan context requires particular understanding of differentiated vulnerabilities. The exposure to climate related impacts will increase and will likely lead to exponential increases in economic loss and suffering if the implementation of priority adaptation measures. Without these measures there will be a more difficult situation in already under significant negative economic and social impacts of climate change disasters such as droughts and floods.

During the last decades, integrated economic modelling has been extensively used to as a prominent tool for guiding, evaluating and implementing water policy decisions.[4-7] This kind of models is able to consider the economic behavior of water users and many economic principles that control water allocation.

Based on the cited elements, this paper aims to present a novel application of Agro-economic modeling framework that is used to assess climate change impacts in the Ait Ben Yacoub Basin by focusing on the agricultural, socio-economic and hydrology systems. The novelty of the approach presented here concerns the ability of this integrated framework to take into account different processes agronomic, economic and hydrologic ones occurring at different scales. Thus, this research takes a step forward in agro-economic modeling to advance in the analysis of climate change repercussions in irrigated agriculture systems starting from crop level to the farm and also the water system levels. The adoption of this integrated approach, this paper evaluates the socio-economic impacts of a severe climate change scenario.

2. Material and Methods

2.1 Overview of the Model

To respond to the problems and challenges of optimal water management to face to climate change, we propose a Agro-economic Modeling framework. The model developed integrates agronomic, hydraulic and socio-economic data. It can simulate the behavior of farmers in response to climate change taking into account competition for resources.

The proposed approach is based on nonlinear optimization techniques. It's a hydrological and economic model that uses water resources in order to maximize the profit at the level of the basin while taking into account a set of constraints which are divided into hydrological, agricultural and resource availability constraints. One major contribution of this model is a detailed disaggregation by spatial units (hydrological units, cropping areas, and grazing land), by agricultural production systems (irrigated and rain-fed crops) and by farm sizes.

The Positive Mathematical Programming Method (PMP) approach, as suggested by Howitt, has been used to calibrate the models.[8] For reasons of lacking strong arguments for other type of functions, a quadratic cost function is employed (exceptions: PARIS and HOWITT).[9] The variable cost function to be specified is:

$$\mathbf{Cv = Ax + \frac{1}{2} B\, x^2} \tag{1}$$

Cv: Quadratic cost.

A: Parameters associated with the linear term.

B: Parameters associated with the quadratic term.

However, the objective function of non-linear programming problem is composed of a quadratic cost calibrated using observed area of crop.

$$\mathbf{Max\ Z = px - Ax - \frac{1}{2}\ B\, x^2} \tag{2}$$

Subject to

$$\mathbf{Cx \le D\ [\lambda]}$$

$$\mathbf{x \ge 0}$$

Where

Z: objective function.

p: product prices.

x: production activity levels.

C: coefficients in resource constraints.

D: available resource quantities.

λ:dual variables associated with the resource constraints.

The codification of this model was written in GAMS (The General Algebraic Modeling System); where data, assumptions, constraints and results are obtainable from the authors upon request. The models was calibrated and validated compared to the observed situation with reference to 2010-2011 seasons.

2.2 Data: Study Area 'Ait Ben Yacoub'

The study area named "Ait Ben Yacoub" is composed of two watersheds: Lhardane basin and Akhnig basin. It is located in the east of Morocco and characterized by a semi-arid climate where water is a limiting factor shown in Figure 1. Thus, this situation constitutes an unfavorable condition for a productive and competitive agriculture. Irrigation water resources consist, on the one hand, mainly by water from the source of "Ain Laarais" share of the major most sources of region with a rate flow of up to 245 l/s and there reviews the other hand, exploited by groundwater through wells and boreholes dug by farmers.

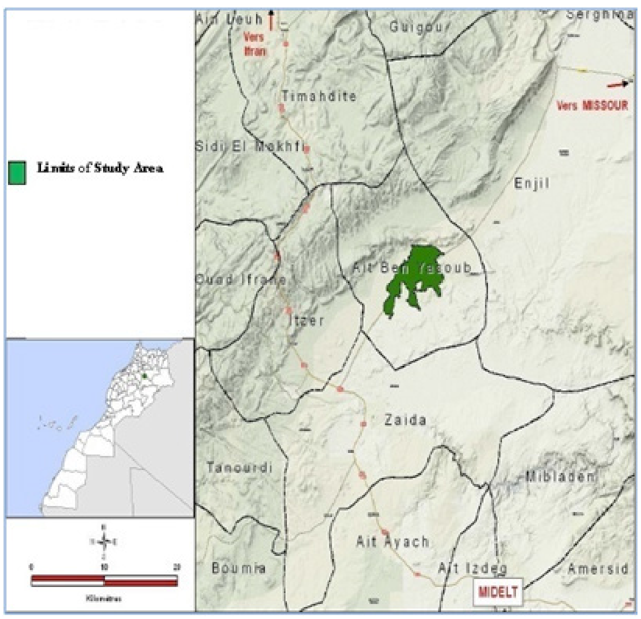


Figure 1. Situation and limits of study area.

Agricultural area in the Ait Ben Yacoub region is equivalent to 60 000ha including only 2585ha of irrigated area and 945 ha of rain-fed area The irrigated area is characterized by traditional agriculture based mainly annual crops and especially cereal with the presence of apple orchards and some winter vegetables, especially potatoes.

The crop occupation in the study area is characterized as follows in Table 1:

Table 1. Land occupation (crop year 2011)

Crop	Area (ha)	% UAA cultivated
Wheat	380.3	19.32
Durum wheat	547.,2	27.8
Barley	592.3	30.09
Maïze	150	7.62
Total cereals	1 669.8	84.84
Alfalfa	3.8	0.19
potato	5.8	0.29
Apple orchard	288	14.63
Olive orchard	1	0,04

The type farms in the study area is sized as follows in Table 2:

Table 2. Representative farm type in "Ait Ben Yacoub area"

farm type	sizeAverage	effective	total size (ha)
S_farm	Less than 2 ha	95	164
M_farm	between 2 and 5 ha	50	228
L_farm	between 5 and 10 ha	59	519
XL_farm	More than 10 ha	58	1989
Total		262	2900

At the present, the water issue in the basin is becoming more and more critical. Thus, water saving represents now a major problem because of the conflict in uses and environmental pressures reached. Furthermore, climate change will add further top pressure on the already stressed water system and consequently will generate additional challenges for the irrigation sector.

2.3 Scenarios

Two types of scenarios are used: Reference Scenario and climate change Scenario.

2.3.1 Reference Scenario (REF Scenario)

The chosen reference year for this study corresponds to the 2010-2011 season. This basic scenario will reflect the use conflicts of the allocation of water in "Ait Ben Yacoub" region and consequently used as a reference for comparing the results for the different scenarios simulated in the model.

2.3.2 Climate Change Scenario (CC Scenario)

This scenario is adopted in order to provide an idea and a vision about the behavior of farmers under water scarcity conditions. It permits also to simulate the impact of the of 50% reduction of water allocation, groundwater recharge and rainfall at the basin level.

3. Results and Discussion

The outputs of the integrated model developed in this study include several variables: hydrological, agronomic, economic and social ones. In this analysis, particular importance will be given to the analysis of the impact of climate change on the socio-economic component. In this paper, the results of the assessment of climate change impacts in "Ait Ben Yacoub" commune are presented for four selected indicators: Poverty rate, Vulnerability index, Gini index and farm's income . These indicators reflect the socio economic impact of climate change and the potential for adaptation.

Figure 2 demonstrate that climate change will produce significant reductions of region's income from 68.9to60 million USD (United States dollar). This reduction in the income concerns all types of farms but the small farms will be most vulnerable ones to climate change. Their vulnerability comes both from different socioeconomic, demographic and policy trends reducing their capacity to adapt to change. Small farms is used to describe farms with an area less than 2 hectares, where cereals are the principal product and mainly for self-consumption by using family labor and for which the farm provides the main source of income. The model results show that aggregate yields of cereal in climate change scenario are likely to show a decrease of approximately 30% which explains their extreme vulnerability to climate change. In climate change Scenario; their income will become deficient Figure 2. A deficit in income will probably be compensated by livestock production. In fact, there is a need to develop the livestock component in the model in a future work to better understand the decisions of farmers.

Table 3 illustrates the social impact of climate change on agriculture farms. In the reference scenario, without climate change for the two basins, 36% of the population lives below the national poverty line corresponding to 352.8 USD in rural areas[3] This rate includes only small farms (less than 2 hectares). Comparing the results of the model with the poverty rate estimated by the HCP in its report "poverty map" published in 2007, close to 17%, a large underestimation of poverty is observed at the regional level, which may limit the effectiveness of adaptation policies to climate change.

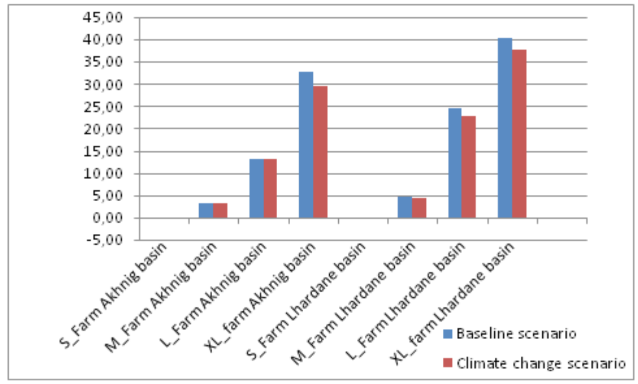


Figure 2. Climate change on farm income in 0.1 Million UDS.

The disproportionate impact of climate change between the different countries of the world is totally accepted. Several economic models have demonstrated the inequalities of incomes between different countries and region of the world, but they failed demonstrating the inequality of income within the same region or basin. It is one of the most obvious gaps in their studies. In response to this, the current developed model for this study integrates the inequality component of income within the region and watershed by calculating the Gini coefficient.

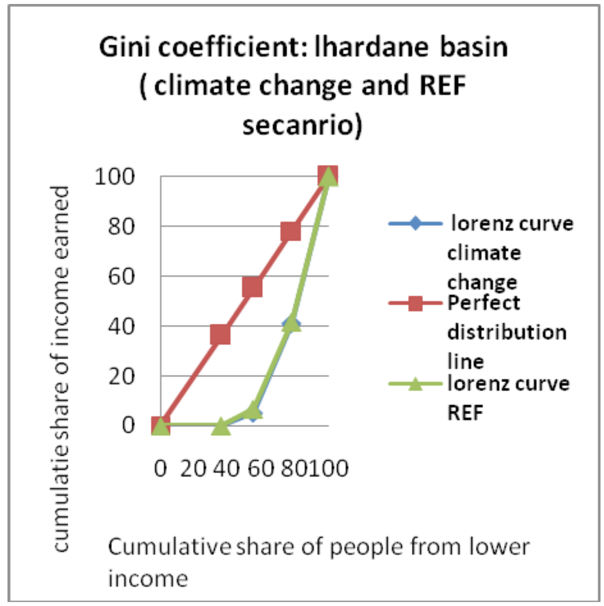
The Gini index is a measure of the income statistical dispersion of a population. This number, which ranges between 0 and 1 and is based on residents' net income, helps to define the gap between the rich and the poor. A Gini index of zero expresses perfect equality and A Gini coefficient of 1 (or 100%) expresses maximal inequality. This index constitutes an important indicator for the analysis poverty and inequality in a country or region, but it should not be incorrect for the measurement of wealth. A wealthy country and a poor country can have the same Gini coefficient, as long as they have similar income distributions. The national Gini index is estimated between 0.3 and 0.1 in rural areas and 0.19 and 0.09 in urban areas.[3]Table 3 describes the important differences in Gini Index for the different studied agricultural areas.

Table 3 shows the Gini coefficients ranging between 0.55 and 0.47, depending on the basin, relatively higher than the world average near to 0.52.[10] This result also demonstrates a significant income distribution inequality within the same region and the same basin. For scenario of climate change scenario, a slight reduction of Gini coefficients is found (15% for Akhnig basin and 20% for Lhardane basin), which contradicts the known hypothesis: Climate change intensifies income inequality Figure 3. This result can be explained by the particularity of the socioeconomic types of farms in this region. Thus, Large farms of this region are characterized by large agricultural areas and at the same are not well developed in their management mode: low capitalization (low capitalization), restricted number of crops, traditional technology. In fact, this situation which limits their capacity to adapt to climate change (which increases the vulnerability). Indeed, on a long-term scale, climate change will increase the tendency to make poor all types of agricultural farms and the Gini coefficient will decrease gradually. In fact, there is an interest to take into account of other socio-economic criteria in addition to farm size in a coming future work in order to classify farms and therefore distinguish farms that resist and adapt best to climate change.

Figure 3. Social impact factor of climate change, comparison of Gini coefficient.

	Akhning basin		Lhardane basin	
	Baseline scenario	CC Scenario	Baseline scenario	CC Scenario
Poverty rate	36.08	36.08	36.19	36.19
Vulnerability index	0	19.00	0	0.00
Income Gini coefficient	0.55	0.47	0.64	0.51

Issues of climate vulnerability and equity are fundamentally about accountability for the causes of climate change and responsibility for helping communities and vulnerable populations prepare for the effects. Social science can assist by framing questions and designing research to clarify disproportional effects of climate change and inequities associated with access to climate information and processes and also can improve the results of the model , allow better anticipation of the behavior of the model to climate change and will contribuer to understanding of how human populations differ in their responses to climate change. Research that takes into account the relationships rural-urban may be particularly useful in understanding adaptive capacity. The ways in which access to information, education, and technology contribute to climate change adaptation and mitigation planning are not yet well understood,though often deemed important.



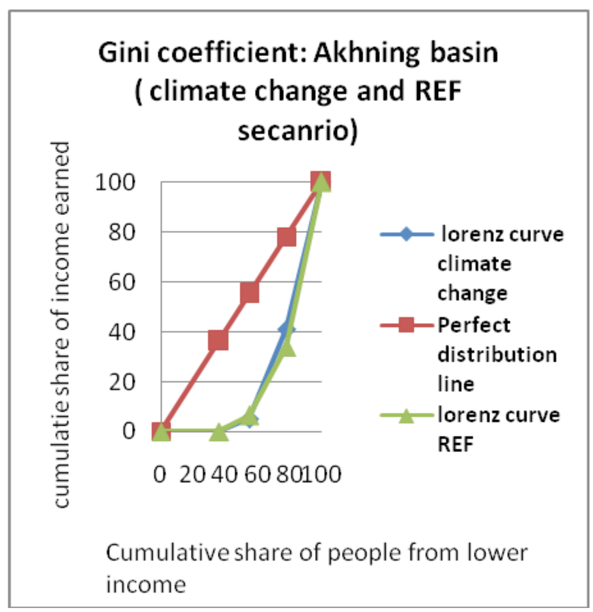


Figure 3. Social impact factor of climate change, comparison of Gini coefficient.

4. Conclusion

This research has contributed to evaluating the socio economic impact of climate change on agriculture farms by addressing the processes that occurs at different scales including crop, farm, irrigation community and basin levels. The integrated modelling approach that has been applied, which combines agronomic, hydraulic and socio-economic analysis, can support adaptation decision making. The ait ben yacoub region case study, an illustrative example of critical water and climate interactions, permitted to illustrate this multi-scaleand interrelated nature of climate change vulnerability and adaptation. The model results evidence the multi-dimensional effects and disproportionate effect of climate change on agriculture sector. The Small farms will be most vulnerable to climate change. Their vulnerability comes both from various socioeconomic, financial and policy trends limiting their capacity to adapt face to climate change. Large farms also will suffer impacts of climate change that will be locally specific and hard to predict, low technology, restricted ranges of crops, low capitalization, and diverse non-climate stressors will tend to increase vulnerability. In the absence of rapid and full adaptation, the consequences of long-run climate change could be even more severe.

5. Acknowledgements

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