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Modeling Agronomic And Economic Flows Upstream Of Transversal Watersheds Of The Niger River: Kourani Baria Watershed Case I

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Abstract:
Background: *The Niger River Valley has enormous agricultural potential that is poorly exploited and is deteriorating due to negative externalities generated by poor agricultural practices and high density of wandering livestock. This situation leads to severe shortages of food resources for both humans and livestock. There is a need for a management system. To manage negative externalities, theoretical tools have been proposed, including direct or indirect taxes, regulations and negotiations. Most of the tools are not applicable in the context of agricultural externalities, which are diffuse and difficult to estimate in order to establish a solid implementation framework. However, several water and soil conservation techniques have been tested and deemed relatively effective in reducing erosion externalities in a watershed. These techniques are not spontaneously implemented by the stakeholders concerned. The payment system for environmental services appears to be more efficient and provides an ideal framework for effective implementation of anti-erosion measures. This work aims to simulate states of nature in order to propose an economic tool for a sustained implementation of anti-erosion measures such as soil and water conservation upstream of a transversal watershed of the river.*
Materials and Methods: *Focus group and questionnaires were used to collect data in Kourani Baria Watershed. The sampling was systematic in order to get a better representativity of all the diversities and complexities that exist in the management and exploitation of the watershed resources. Random sampling was used to select 30 cereal farmers at the top of the watershed, 20 cereal farmers in the intermediate basins between the top and flood zones and 35 livestock farmers exploiting the resources of the basin. All primary and secondary data are pre-processed before entering into the model. A recursive bio economic model was developed, using GAMS welfare, to maximize the income of watershed under different constraints. It takes into account all the intra-annual and inter-annual techno-economic interactions to assess the feasibility and efficiency of a payment system for environmental services at the local level. Different states of nature are simulated taking into account the adoption of soil and water conservation techniques, with and without subsidies.*
Results: *Land is allocated on the basis of comparative advantages between grain production and fodder crops. Human and animal populations are increasing the 40 first years of the simulation. The populations increase as long as there are possibilities for producing food through the cultivation of arable land and stabilize when the possibilities for increasing food resources are exhausted. The model does not limit the development of breeding since its parameters are not taken into account. The total watershed income increases during 50 years before stabilization. During the first years of the simulation, erosion increases. At first, it is greater in cultivated fields than in livestock systems. Gradually, livestock causes more and more erosion due to the increase in the number of nomadic and sedentary livestock. Fortunately, the model allows to control and manage the erosion by implementation of soil and water conservation techniques. Farmers can adopt some good practices in their field to avoid erosion but these actions are insignificant to stop the erosion throughout the entire watershed. There is a need for other source of funds, such as subsidies, to help stabilize upstream externalities in watersheds.*
Conclusion: *the sustainable management of watershed resources is conditioned by the proposed rate of subsidy for carrying out anti-erosion works upstream.*

Keywords: *Erosion, degradation, damage, soil and water conservation techniques, payment for environmental services, incitation, Upstream, Watersheds,*

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I. Introduction

The Niger River Valley offers potential for agricultural development. Unfortunately, this potential is poorly exploited and deteriorating due to problems of pollution, invasion by aquatic plants, erosion and silting. It has an agricultural potential estimated at more than 2.8 million hectares, only 324,610 ha are developed in 10 countries of the river basin[1]. Many hydro-agricultural development projects are envisaged in the Niger River Valley[2] with more than 390,000 ha of irrigable land in Mali and Niger[1] only. The Niger Valley is a very important site for West African countries in general and for Niger in particular.

In Niger, upstream of the transversal watersheds, two main groups of users practice agricultural activities. Rain-fed cereal farmers aim to feed themselves as much as they can under various production constraints. They develop and overexploit the maximum amount of arable as well as unsuitable land in order to satisfy the needs of an ever-growing population, regardless of the damage that this activity causes. The corrective fallow system for soil fertility regeneration is no longer implemented[4,5] thus exposing the land to further erosion[5,6,7,8]. Farmers on this site practice traditional, extensive agriculture which degrades their own land and negatively impacts the surrounding land dedicated to fodder production and the land downstream. As a result, productive capacities and the areas of agricultural and fodder land decrease gradually. If no change in the agricultural practices is made, the land will become marginal, unsuitable for agriculture.

Besides agricultural activity, animal herders main objective is to ensure the multiplication and feeding of a maximum of livestock. To do this, they exploit more and more fodder lands[3] which, are in addition decreasing in favor of cereal crops. Meanwhile, the need for fodder resources continues to increase given the growth rates of local herds and those in seasonal transhumance. Overall fodder production is declining due to the reduction in fodder lands, the duration of fallows[4, 5] and the decline in the productivity of the lands due to their degradation and loss of fertility[5,6,7,8]. Despite all these constraints, grazing is not regulated, access is free and animal loads are not limited. The very high animal densities per hectare has resulted into overgrazing[2, 6, 9] of the transversal basins of the Niger River which is also an indirect cause of negative externalities leading to erosion.

These types of resource exploitation degrade arable land because of alluvium that silts up agricultural resources and infrastructure. They create negative externalities, including erosion that reduces land fertility and silts up agricultural resources, particularly in downstream land[10, 11, 12, 13]. They are the major causes of a continual decrease in the total exploitable areas, a decrease in land productivity and regular increases in production costs. They ultimately result in severe shortages of food resources for ever-increasing populations of both human and livestock, thus leading to disasters[14, 15,16] and famine if no corrective actions are taken[17].

Erosive externalities can be controlled by various anti-erosion techniques. In cultivated fields, water and soil conservation structures have low costs and are hence bearable by producers[18,19, 20]. Organic amendments, good agricultural practices, plant production works, etc. are beneficial and can help improve the yield and income of households. Bare slopes are treated with anti-erosion structures to reduce water runoff and thereby improve soil quality[19, 21, 22, 23, 24] for better crop production [7, 19, 22]. The treatment of koris is more technical and requires more resources. All these techniques are efficient, but they must be reasoned and integrated at the watershed scale to hope for overall efficiency. They are not spontaneously adopted by all stakeholders, despite the agronomic and economic advantages they provide and most of them have costs that are not supported by upstream producers.

Several approaches have been theoretically developed to correct environmental damage. One approach is the direct taxation of negative externalities at source by applying the principle of the "Pigouvian tax". Unfortunately, it is both difficult to implement and rarely applied in the context of agropastoral activities[25] or diffuse pollution of agricultural origin[26]. Agricultural externalities are difficult to quantify and have no market value on the goods market. They are not linearly linked to a given technique or a specific production factor. Furthermore, agropastoralists do not agree to pay a tax since they apply the principle of the first exploiter, common in international law, for the development of shared watercourses[27]. However, indirect taxation can be used in the case of agricultural pollution, although imperfect and inequitable. It allows avoiding the difficulties of evaluating the costs of externalities and is justified in contexts where monetary evaluations of services are complicated to carry out. In such situations, the amount of the tax must be determined in a flat-rate manner or by negotiation and not on the basis of cost estimates[26]. The regulatory approach sets standard norms aimed at reducing negative externalities and improving positive externalities, in order to meet the requirements of minimum efficiency. It defines a level of effort to be achieved by minimizing social costs. It is interesting in a context where environmental services are difficult to evaluate in monetary terms. It can be used to estimate the quantities of services produced and the costs. These tax and regulatory approaches can help to initiate bargaining between suppliers and demanders of environmental services but do not allow concluding voluntary and efficient contracts based on the win-win principle, obtained by negotiation.

However, negotiation allows finding an operational equivalence between payments and corresponding services[25]. One of the famous tools is the payment system for environmental services[28, 29, 30] which involves all users and is based on the "win-win" principle in accordance with market logic[20]. It identifies the victims and the accused, who must pay for the damage caused and who has the right to be paid to reduce the damage[30]. This system has the advantage of offering operational, effective, inexpensive and sustained solutions.

In the context of the transversal watersheds of the Niger River, negotiation seems more appropriate to hope for a reduction in the damage of externalities at the source by setting up a payment system for the implementation of soil and water conservation techniques and their maintenance. This work aims to simulate states of nature in order to propose an economic tool for a sustained implementation of anti-erosion measures such as soil and water conservation upstream of a transversal watershed of the river.

II. Material And Method

The methodology was based on the collection of primary and secondary data to develop a bio economic model. Different stages of the process are shown diagrammatically in Figure 1.

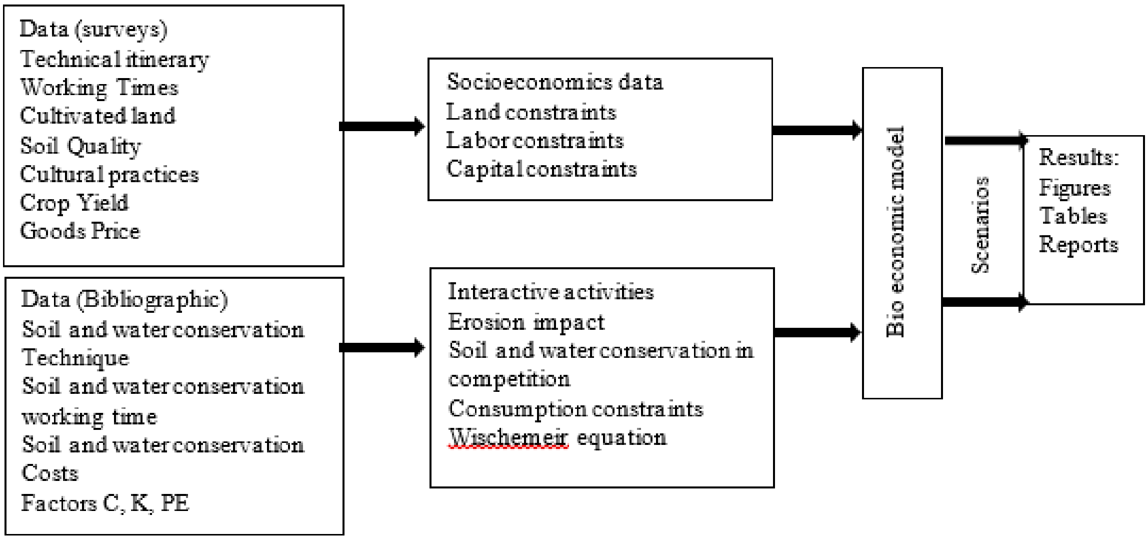

Figure 1 : Bio economic modeling Diagram

Data collection area

The Kourani Baria (KB) watershed is located 90 km from Niamey on the Niamey-Tillabéry road, on the right bank of the Niger River, between 14°44’24.5 North and 001°18’04.7 East. It has three koris, namely the “Yalalé”, the “Gorouol” and the “Kossonramé” which establish bridges for the flow of alluvium from upstream to downstream. These koris are overlooked by pedi-glacis, dune massifs and cross the terraces and lowlands of the river. Pedi-glacis are thin silty-sandy soils, mainly reserved for pastures, dune massifs and medium terraces are exploited for cereal crops and finally the lowlands are developed for irrigated rice cultivation. Upstream agropastoralists promote erosion and rainwater runoff which sands up and floods downstream agricultural activities (figure 2) in particular the case of the irrigated perimeter of Kourani Baria (750 ha) created in 1986.

Sampling

Prior to sampling, five focus groups were conducted in the study area. The synthesis of the focus group interviews made it possible to understand the spatial genesis of the degradation, of plant cover and of erosion in the watershed. It also highlighted the natural resource management experiences of producers in the study area. Based on this synthesis, three main operating areas along the upstream were identified based on agricultural practices and the externalities generated: (1). Producers at the top of the watershed do not experience any negative externalities management and pollute other homelands; (2). Others are between the top and the unflooded down areas of the watershed have experienced negative externalities (including damage to rainfed cereal fields) and implementation of soil and water conservation techniques; (3). Alongside rainfed producers, livestock herders exploit fodder and create negative externalities. Thus, the sampling is carried out in clusters that take into account the main groups of actors exploiting the upstream resources. It was systematic in order to be representative of all the diversities and complexities that exist in the management and exploitation of the watershed resources. Random sampling was used to select cereal farmers for the administration of the questionnaires. Sampling livestock herders was difficult because of their mobility. For this group the questionnaire is administered systematically as they are met on the grazing land.

Thus, data were collected from 30 cereal farmers at the top of the watershed, 20 cereal farmers in the intermediate basins between the top and flood zones and 35 livestock herders exploiting the resources of the basin. All primary and secondary data are pre-processed before entering into the model.

Model

A recursive bio economic model (figure 2) was developed, using GAMS welfare, to maximize the income of a watershed under different constraints. It takes into account all the intra-annual and inter-annual techno-economic interactions to assess the feasibility and efficiency of a payment system for environmental services at the local level.

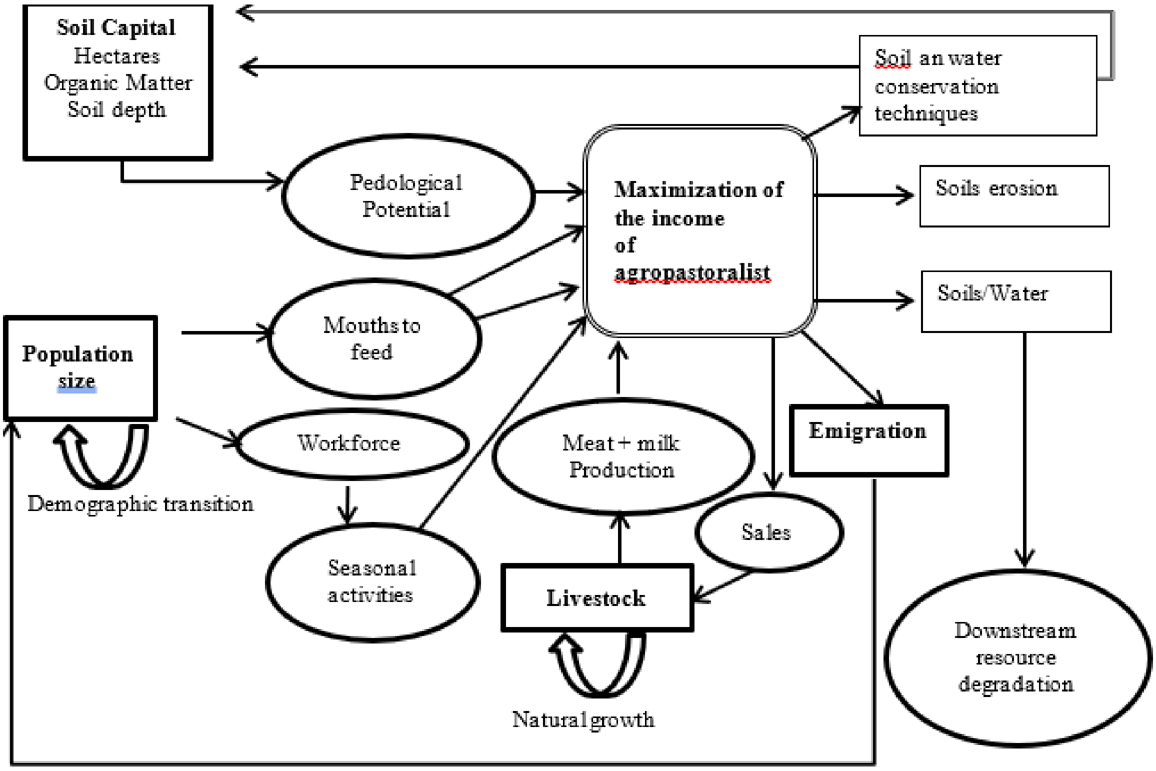

Figure 2 : Recursive upstream watershed

The upstream model maximizes the overall income from upstream agropastoral activities by taking into account subsidies for the implementation of CES techniques.

- Max ((Q(cp) x Pc + Q(e) Pa) + Surf(TCES) x Sal(CSE) +rev Mig
- Under constraints: Land, Labor, Capital and erosion

With:

Q (cp) :	quantity of rainfed cereals produced
Pc:	sales prices of cereals produced
Q(e) :	Animal weight gains
Pa:	Animals price
Surf (TCES):	surfaces fitted out with soil and water conservation techniques
Sal (TCES):	subsidy for the implementation of soil and water conservation techniques
Rev (Mig):	migration income

The model made it possible to represent all the flows of agronomic interests and all the flows of economic interests at the scale of a transversal watershed.

Scenario

The scenario represents the management of the natural resources of the watershed by agropastoralists alone. Different states of nature are simulated taking into account the adoption of soil and water conservation techniques, with and without subsidies. Several simulations were carried out to analyze the behavior of upstream agropastoralists when subsidies are offered for the implementation of soil and water conservation techniques. Simulations were run without any implementation of soil and water conservation techniques to represent the current evolution of the degradation of watershed resources, mainly the upstream irrigated perimeter. Tables and figures are analyzed.

III. Results

Resources evolution

The model distributes arable land between cereal crops and livestock. It makes a comparative choice based on the advantages, between crop rotations on the one hand and activities carried out upstream on the other. First, it chooses to cultivate a good part of the fertile land and leaves the rest fallow. It reserves another part of the basin's land for fodder. But, a few years later, the fallow disappears, all the land is put into food crops or reserved for fodder production. Thus, the fodder potential increases for a few years and in relation to that, the model reflected an increase in livestock number. The model also develops nomadic herding trend in the sub-watersheds and sedentary herding trend related to the investment of profits from the sales of cereal products in animal production. In some basins, sedentary livestock herding is developing at the expense of migrant livestock herding on the basis of the availability of fodder resources supplemented by crop residues. By contrast, migrant livestock herding and is developing at the top of the basin where there is still enough fodder land.

The model predicts upstream population increase during the first 40 years. By the fortieth year, the population will have doubled and thereafter stabilized. The population increase rate is identical in the two upstream sub-basins (Figure 3). During these forty years, the model has the possibility of increasing the population by 3.9 per thousand as long as there are possibilities to feed the population by producing more through the exploitation of all the lands, including the marginal ones. These evolutions of human and food resources are proportional until the use of all available natural resources. From the fortieth year on, food resources become constant. The model no longer allows for mass procreation because of the insufficiency of food resources.

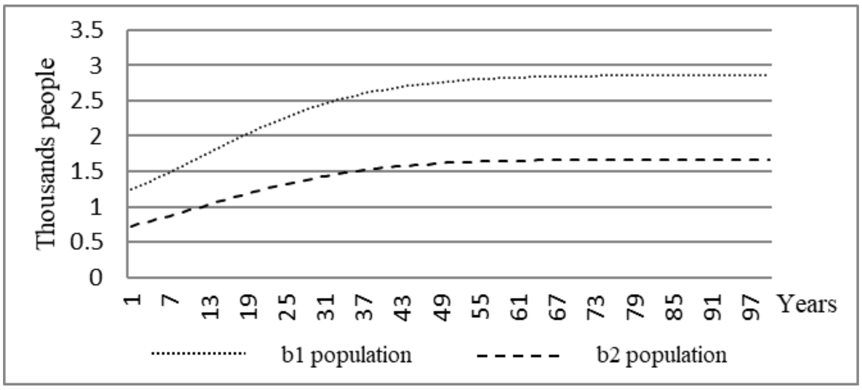

Figure 3 : Human population projected evolution in upstream

Income evolution

The model maximizes the total income of the basin (figure 4). It generates income from migrants' remittances of resources, animal sales and cereal sales but does not consider the quantities of non-commercialized cereals (self-consumed and offered). It predicts an increase in income from migration and livestock herding for more than forty years before stabilizing. Income from the sale of cereals remains stable throughout the simulation.

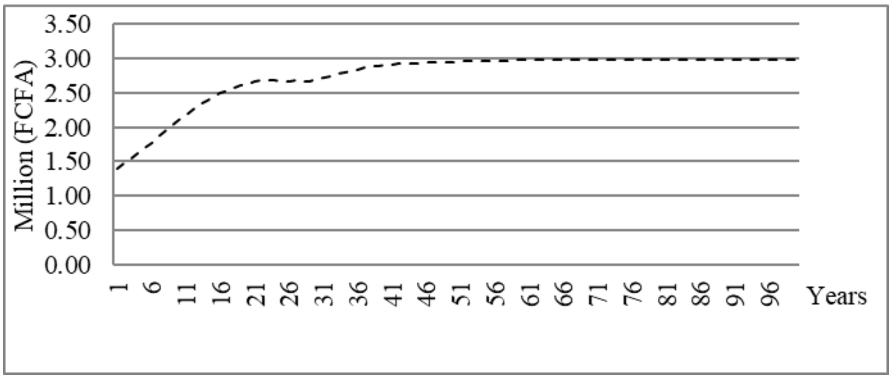

Figure 4 : Total projected income evolution in upstream

The discounted overall income increases (Figure 3) thanks to the increase in agricultural production and especially thanks to the increase in herd numbers. It stabilizes after 50 years, when the population stops increasing and the number of animals stabilizes. From the 50th year, the possibilities for improving income in the watershed are exhausted. An increase in the overall income of the basin would only be possible from sources other than those already analyzed in this model.

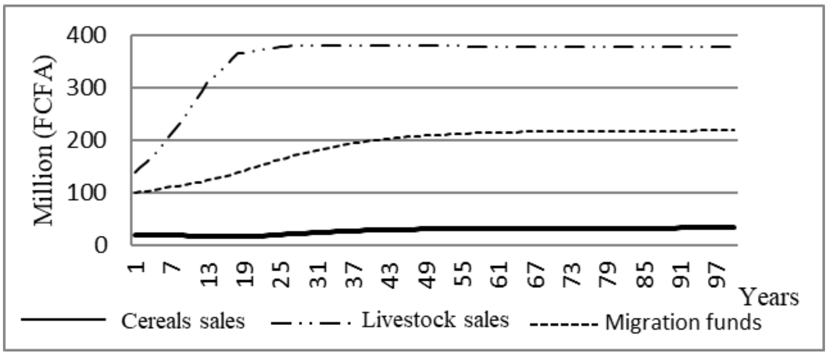

Figure 5 : Projected income evolution by activities in upstream

The discounted overall income per capita is also quite high given the high profitability of livestock farming and the additional income from temporary migration. It follows the same evolution as that of the overall income of the basin. The income per capita increases in the first 15 years, decreases slightly in the next 50 years, then stabilizes from the 70th year when the population growth stabilizes. This evolution is illustrated by Figure 5.

Erosion management upstream of the basin

Erosion increases in the watershed during the first years of simulation due to the adoption of poor agricultural practices, the development of marginal lands and poor livestock management (livestock populations, livestock wandering and fodder resources). During the first years of simulation, agricultural erosion is more important than that caused by animal herds. Unfortunately, with time, livestock causes more and more erosion due to the increase in the populations of nomadic and sedentary livestock with regard to the advantages they offer to cereal producers. The evolution of animal erosion is proportional to the evolution of their numbers. This type of erosion subsequently stabilizes because the model no longer allows additional livestock number since the management of the erosion it would cause would cost more. Furthermore, the control of animal erosion is not taken into account because the two main ways of regulating animal numbers and access to resources are done by the establishment of rules and negotiations, which are not taken into account in this model. It chooses the best allocations of reproductive resources under several production constraints. For instance, it does not limit the number of wandering animals because it finds it interesting.

On the other hand, the model allows the implementation of soil and water conservation in cultivated fields in order to control and manage agricultural erosion. It chooses to implement good cultural practices in the cultivated fields of agropastoralists because they are beneficial. It chooses to continue to carry out cultural practices and to develop more surface area every year. It maintains the old soil and water conservation developed in past years and cumulatively. Thus, the developed areas in each sub-basin increase regularly every year. The adoption of cultural practices makes it possible to increase cereal yields and reduce land losses through erosion. Furthermore, cultural practices are not expensive. They require only few additional costs and are carried out with low investment efforts. However, soil and water conservation techniques have a lifespan of around ten to twenty years depending on the type of structures and become obsolete if these structures are not maintained.

Funding of soil and water conservation technique realization

The costs of adopting soil and water conservation techniques are proportional to the area under cultivation and the rate of adoption of innovative cultivation practices. These costs are higher in cultivated areas and increase progressively during the first fifty years before stabilizing when erosion damage is controlled (figure 6).

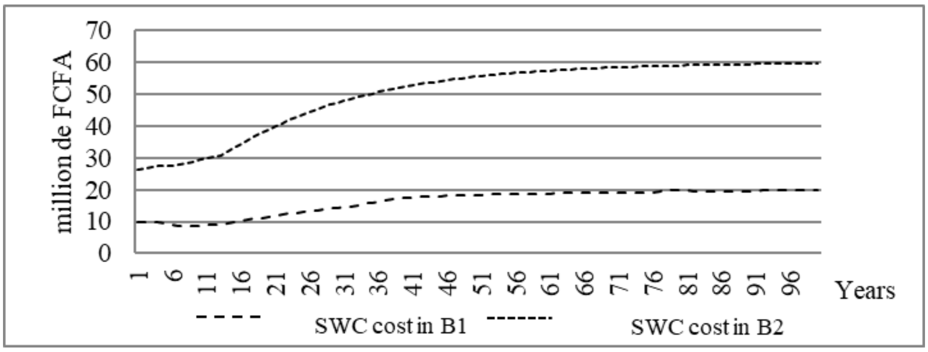

Figure 6 : Evolution of soil and water conservation costs by sub-basin

The model chooses self-financing the implementation of soil and water conservation techniques by upstream agropastoralists only when these techniques are profitable for their agricultural activities. It chooses to self-finance anti-erosion developments that bring profits to upstream producers. It only adopts cultivation practices that improve the fertility of cultivated fields and increase crop yields/household incomes.

The costs of self-financing are proportional to the total area cultivated and are higher in certain parts of the sub-watershed. They are significantly lower than the funding requirements to finance the implementation of soil and water conservation techniques across the entire transversal watershed. This difference must be financed by other sources outside the upstream farming systems (subsidy from rice producer, Government, Development projects and NGOs, for example).

Self-financing of soil and water conservation by agropastoralists is insufficient to reduce externalities across the entire watershed. Erosion remains high despite the implementation of less erosive cultivation practices (such as the no-till practice or deep plowing) in cultivated fields. Fertile land decreases regularly during the first 20 years of operation while damage increases during the same period. Several thousands of agricultural lands become marginal lands, unfit for agriculture after about thirty years (Figure 7).

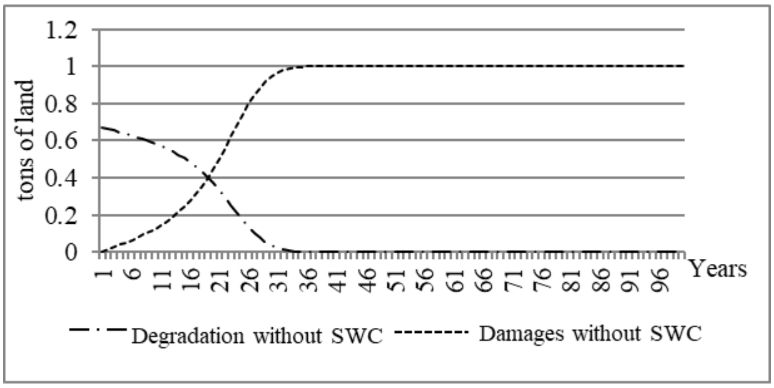

Figure 7 : Evolution of agricultural land without subsidy

Self-financing of soil and water conservation technique by agropastoralists must be accompanied by external investments in order to preserve and improve the productivity of the resources across the watershed.

To that end, it would be necessary to exploit other mechanisms for regulating negative externalities to carry out soil and water conservation that are not self-financed by agropastoralists. This would ultimately be highly beneficial, drastically reduce erosion and improve the performance of irrigation infrastructures.

However, the model adopts soil and water conservation technique in the glacis and treats the koris if these techniques are financed or subsidized by other actor. The resources of the basin are better protected, in particular the entire irrigated perimeter. Indeed, external funding could bare the heavy costs related to the treatment of the parts not treated by upstream users who find that these investments are not beneficial for their agropastoral activities. Furthermore, the construction costs of soil and water conservation structures (half-moons, zaï, stone bunds, gabion thresholds) exceed by far the investment capacities of upstream subsistence farmers' and herders' activities. Taking these costs into account in the production costs of agropastoralism would lead to the total disappearance of these legitimate activities. It is therefore imperative to subsidize the implementation of soil and water conservation techniques in the partially unexploited upstream areas in order to make possible their exploitation end ensure the sustainability of planed irrigated infrastructures. The subsidies are proportional to the implementation of proven innovative cultivation practices in the fields. They decrease in the first year's then increase for about twenty years before stabilizing during the 1950s.

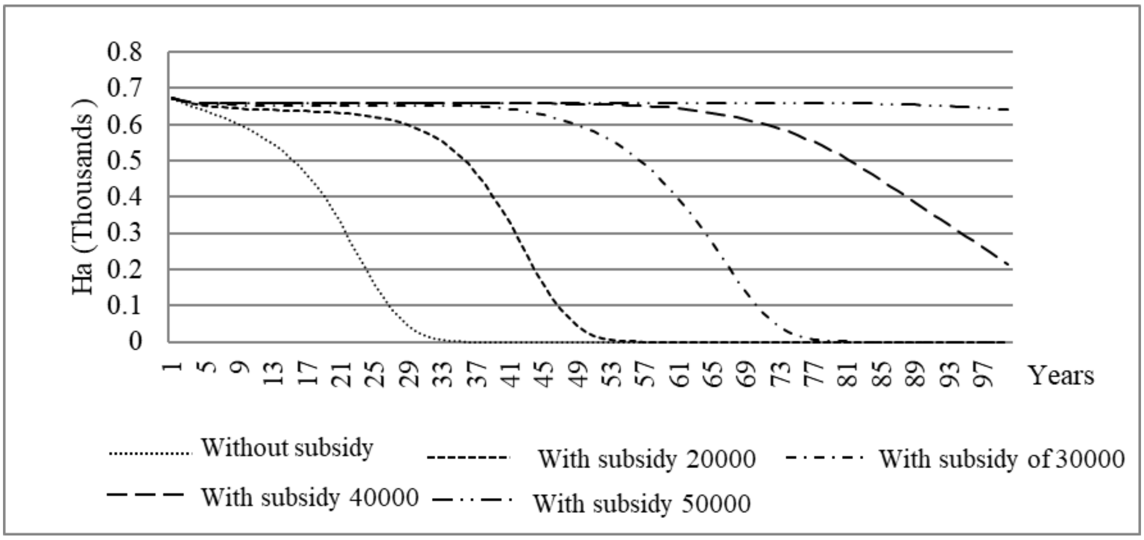

Figure 8 : Soil and Water Conservation Subsidy

The impact of implementing anti-erosion works is simulated using different subsidy rates. Initial simulations show that a subsidy of 25,000 FCFA/ha/year is sufficient to delay the degradation of the basin's resources by around forty years. If the subsidy rate is doubled, the sustainability of the resources is doubled. Subsequently, even a small increase in the subsidy rate is significant enough to reduce the impacts of erosion in the basin (Figure 8).

IV. Discussion

One of the results predicted by the model is that evolutions of human and food resources are proportional until all the available natural resources are exhausted. This result is consistent with Malthus's theory which predicts the balance between food resources and the food needs of the population when agricultural resources are limited. This stabilization of the population (slowdown in growth) corresponds to the hypothesis of the demographic transition, exogenous to the model which stipulates that the population should gradually stabilize towards the middle of the century. This slowdown also explains the definitive migration of a part of the population towards large cities and other countries. Despite everything, each new person brings in more than he costs.

The model predicts unsustainable exploitation of the watershed without the introduction of soil and water conservation techniques, due to population pressure and the development of livestock farming. The expansion of crops and high animal densities lead to significant erosion of the basin's arable land, which will be completely degraded[5, 19]. After few years, there will be less soil to transport in the kori, to the downstream parts of the basin and into the river. Once the arable land has been eroded, a hardened layer that is not arable and difficult to recover appears. Runoff increases but the transport of fine elements will be reduced. This situation is similar to the case of the Nakanbè basin in Burkina Faso described by[31].

The model also predicts the intensification of livestock farming in accordance with the study[32] of Scoones, 2006. Forages based on crop residues are systematically collected to constitute food resources for animals, throughout the Sahel. Similarly, transhumance has been shortened because of the expansion of crops. It is also possible to control, contrary to Hardin's description of the tragedy of the commons, the study[33] of Ostrom, 1990 demonstrates that local communities are generally capable of managing common resources in a sustainable manner.

The simulation results show the advantages of adopting certain soil and water conservation techniques. They do not completely reduce erosion but it is possible to limit it. The real effectiveness of anti-erosion practices is tested in the fields by community actions incentive in several regions. In Niger, many watersheds have been treated in the past, including the lower Tarka valley as part of the implementation of the Lower Tarka Valley Project. Several development actions and incentive policies, such as "food for Work", "Cash for Work" have been successfully initiated as part of soil and water conservation, recovery of degraded land (glacis). The only difficulty with these programs is related to the sustainability of the techniques which is often not taken into account in the actions and is not spontaneously taken into account by the first beneficiaries[34] (Pender and Ndjeuga, 2008). The effectiveness of the impact of the implementation of anti-erosion techniques will be effective when large subsidies are offered to users adopting them in their area. These results are consistent with the results of work carried out by[35] (Fanny le gloux) on the efficiency of payment systems for environmental services.

V. Conclusion

Simulations without subsidies show that the basin resources degrade further after a few decades if no measures are taken to manage the watershed. Without subsidies, the upstream part of the basin will be subjected to more erosion as herds and population increase and overexploit agricultural land and pastures. Without subsidies, the model adopts SWC techniques in cultivated fields, but not enough to reduce the extension of cereal crops and to significantly reduce erosion. On the other hand, it does not carry out soil and water conservation techniques in the glacis and koris which are still significant sources of erosion, especially in watersheds with several Koris. It is then realistic to state that the adoption of soil and water conservation techniques only in the cultivated lands will not produce enough effects to reduce the impacts of erosion in the entire basin.

On the other hand, simulations with subsidies adopt soil and water conservation techniques and increase the sustainability of watershed resources, particularly the irrigated area infrastructures. The model implements cultivation practices in cultivated fields and builds technical soil and water conservation structures in unexploited common areas. Thus, it minimizes damage and loss of irrigated surface area. However, in this scenario, the model does not find it beneficial to reduce livestock erosion as it is insignificant. Consequently, it does not limit the number of wandering animals and allows the development of sedentary livestock farming, which is still erosive.

Furthermore, the model self-finances only a small part of the implementation of soil and water conservation techniques. Other sources of financing should be found to cover the costs related to the implementation of soil and water conservation techniques that are not self-financed by the activities of agropastoralists. It is more interesting to analyze a mechanism for covering the costs related to the sustainable management of the overall basin by other actors, including downstream users who wish to reduce externalities coming from upstream. Indeed, downstream users must finance the implementation of soil and water conservation techniques in the glacis and koris if they wish to reduce the impact of erosion at the level of the irrigated perimeter.

The impact of anti-erosion works will be effective when subsidies are offered to voluntary users for their implementation. The effectiveness will be greater when the subsidies per hectare are high.

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