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

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Abstract:
Background: *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 animal density. These farming systems lead to severe degradation of agro pastoral production system at upstream. It also cause a continual decrease in the total areas exploited, a regular increase in production costs at downstream and finally degrades completely the irrigated perimeter if no management system is undertaken. In this context, it is difficulty to apply direct or indirect taxes to these diffuse externalities using the "polluter pays" principle. These externalities can be controlled by implementing water and soil conservation techniques. Several water and soil conservation techniques have been tested and deemed relatively effective in reducing erosive externalities in a watershed. These techniques are not spontaneously implemented because they are expensive and are not beneficial for upstream poor agro pastoralists. However, the "polluted pays" principle can be applied to finance the treatment of glacis and koris in order to reduce the silting up of the perimeter and increase the sustainability of the resources of the irrigated perimeter. Rice producers generate attractive profits that could finance the implementation of soil and water conservation techniques to increase the sustainability of their downstream activities. The payment system for environmental services appears effective in providing an ideal framework for the effective implementation of anti-erosion works. This work aims to simulate states of nature in order to propose a subsidy for a sustained implementation of anti-erosion measures such as soil and water conservation technique at upstream of a transversal watershed of the river.*

Materials and Methods: *Bibliographic study, focus groups and questionnaires were used to collect data on Kourani Baria Watershed. The sampling was a two-stage stratified random survey. First three main areas were systematically identified to take into account the diversity of farmers and their management of externalities according to the subdivisions of the irrigated area into hydraulic districts (mutual groups of producers). In each area, a simple random draw by cluster was carried out after updating the list of farmers by hydraulic district. Thus, 100 rice farmers were interviewed for the collection of primary data. All primary and secondary data are pre-processed before entering into the model. A recursive bio economic model was developed, using General Algebraic Modeling System 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 rates were simulated to analyze both the possibilities of paying the tax and the sustainability of the irrigated perimeter. Tables and figures are analyzed.*

Results: *The total area reserved for rice cultivation stabilizes during the first 30 years if subsidies are offered for the implementation of upstream anti-erosion mesures. Population decreases slightly from the first year to the 60th years before stabilizing. Livestock numbers increase during the first years of the simulation before stabilizing towards the end. Overall income of the basin increases until the 75th year drive by income from animal production which increases until the 80th year. It stabilizes towards the end of the simulation when livestock farming no longer develops. Erosion increases and leads to loss of cultivated plots in the irrigated perimeter after 30 years. If no anti erosion structures are not carried out to significantly and sustainably reduce erosion damage, particularly alluvial deposits and flooding of cultivated plots, the entire perimeter will disappear. Indirect rice cultivation taxation is possible to finance soil and water conservation techniques in order to control externalities.*

Conclusion: *A payment mechanism for environmental services is feasible at the local level between downstream actors and upstream agro pastoralists. Rice farmers give flat-rate subsidies per area unit to agro pastoralists so that they install water and soil conservation techniques upstream of the watershed.*

Keywords: *Rice, silting up, taxation, subsidy, downstream, watersheds, Niger River*

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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, of which 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] notably more than 390,000 ha of irrigable land in Mali and Niger[1]. The Niger Valley is a very important site for West Africa countries in general and for Niger in particular.

In Niger, upstream of 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 productions factor constraints. At the same time, the main objective of livestock herders is to ensure the multiplication and feeding a maximum number of livestock. They develop and overexploit[3] the maximum amount of arable as well as unsuitable land in order to satisfy their needs regardless of the damage caused. The corrective fallow system for soil fertility regeneration is no longer implemented[3, 4, 5] thus exposing the land to further erosion[5, 6, 7, 8, 9]. 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].

The objective function of rice farmers is to produce more rice in order to generate marketable surpluses under constraints of production factors. They exploit the irrigated perimeter and practice double rice cultivation in controlled irrigation by pumping. Rice cultivation is beneficial for rice farmers and contributes to achieving food self-sufficiency for thousands of rural people. However, this activity is threatened by erosion produced upstream in the fields and pastures, to which is added the erosion produced in glacis (bare) soils and koris. The irrigated perimeter is flooded and silted up, causing a decrease in production and its production potential. These types of exploitation cause a continual decrease in the total areas exploited and regular increase in production costs. They ultimately lead to severe shortages of food resources for an ever-increasing population and animal numbers, thus leading to disasters[13, 14, 15, 16] if no corrective actions are taken[17].

In this context, direct tax cannot be proposed to control these erosive externalities at source by applying the "polluter pays" principle [18, 19]. Furthermore, the economic viability of upstream agricultural activities will be called into question with taxation. In addition, upstream producers do not agree to pay a tax since they apply the first operator principle, common in international law, for the development of shared resources[20]. However, the regulatory tool could be interesting in this context where environmental services are difficult to evaluate in monetary terms. The context makes possible to develop an ideal exchange mechanism between the environmental services provided and their monetary equivalents. One of the tools is the payment system for environmental services [21, 22, 23] which involves all users and is based on negotiation, in line with market logic [24]. It distinguishes victims and those accused, who must pay for the damage caused and who has the right to be paid to reduce the damage [24]. This system has the advantage of offering operational, effective, inexpensive and sustained solutions.

These erosive externalities can be controlled by various anti-erosion techniques. In cultivated fields, water and soil conservation techniques have low costs, bearable by producers[24, 25]. These actions improve soil quality[26, 27, 28, 29, 30] and plant production[7, 26, 28]. The treatment of koris is more technical and requires more resources. These techniques are not spontaneously adopted, although they have agronomic and economic advantages. Most of These techniques have costs that are not accepted by upstream producers. Furthermore, upstream producers adopt only some of the soils and water conservation techniques that are beneficial for their agricultural activities. These achievements are insufficient to control the degradation of watershed resources. They are also interested in treating certain parts of the watershed for a compensatory payment. On the other hand, rice farmers are powerless to manage silting and flooding in situ, in the irrigated area. In addition, they do not have the right to freely treat upstream lands that do not belong to them and which would cost them dearly if they were to mobilize physically to do so. It is interesting to analyze an offer of incentive payments to upstream users to carry out effective and sustained soils and water conservation techniques. We are in a context of “polluted pays”. Rice farmers who are victims of erosion must pay upstream users so that they do not pollute them. The flat-rate tax can be used as a fundraising tool to subsidize the implementation of soils and water conservation techniques upstream. 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 technique at 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. The different stages of the process are shown in Figure 1 below.

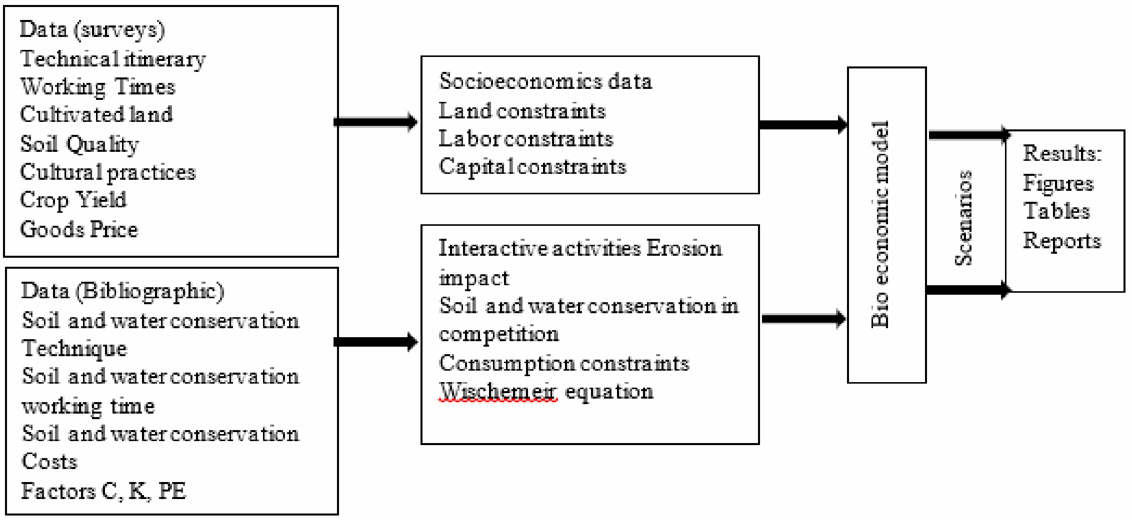

Figure 1 : Bio economic modeling Diagram

Data collection area

Data collection area was Kourani Baria watershed, located at 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 main koris, namely "Yalalé", "Gorouol" and "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 activities promote erosion and rainwater runoff which sands up and floods downstream agricultural activities in particular the case of the irrigated perimeter of Kourani Baria (750 ha) created in 1986.

Sampling

Prior to sampling, secondary data were collected and focus groups were conducted in the study area. The syntheses of these two activities made it possible to refine the problem at the level of the irrigated perimeter and the data collection tools. The sampling was a two-stage stratified random survey. First three main areas were systematically identified to take into account the diversity of farmers and their management of externalities according to the subdivisions of the irrigated area into hydraulic districts (mutual group of producers). The group of producers in hydraulic districts who have experienced flooding: the group of producers who suffered from alluvial deposits and the group of producers who have not suffered negative externalities. In the second stage, a simple random draw by cluster was carried out after updating the list of farmers by hydraulic district. Thus, 100 rice farmers were interviewed for the collection of primary data. All primary and secondary data are pre-processed before entering into the model.

Model

A recursive bio economic model (figure 2) was developed, using General Algebraic Modeling System 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 local level.

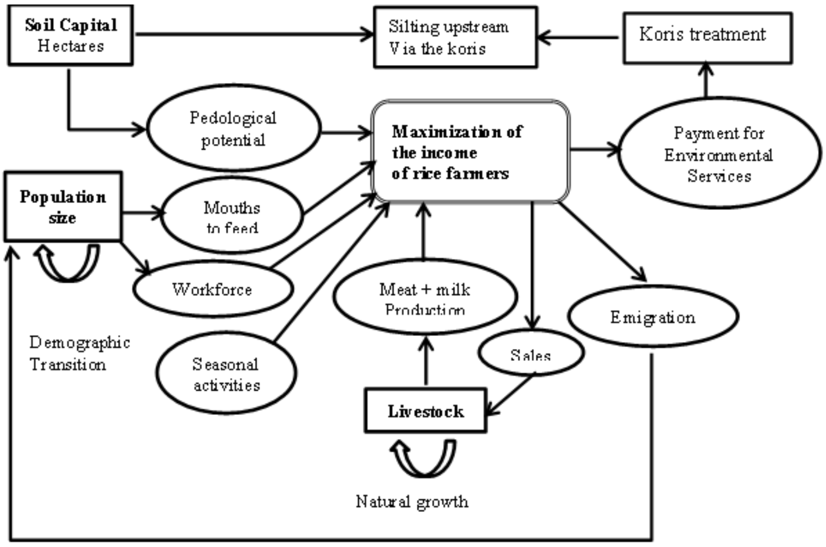

Figure 2 : Recursive downstream watershed

The model maximizes the overall income from downstream activities by taking into account taxation for the implementation of CES techniques.

- Max ((Q(ci) x Pci + Q(e) Pa) + Ta(die)) +rev Mig
- Under constraints : Land, Labor, Capital and Erosion

With:
Q (ci) : Quantity of rice produced
Pci: Sales prices of rice produced
Q(e) : Animal weight gains
Pa: Animals price
Ta (die) Taxation for soils 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 rice farmers alone (figure 3). Different states of nature are simulated without and with indirect taxation of rice farmers. Different rates were simulated to analyze both the possibilities of paying the tax and the sustainability of the irrigated perimeter. Tables and figures are analyzed.

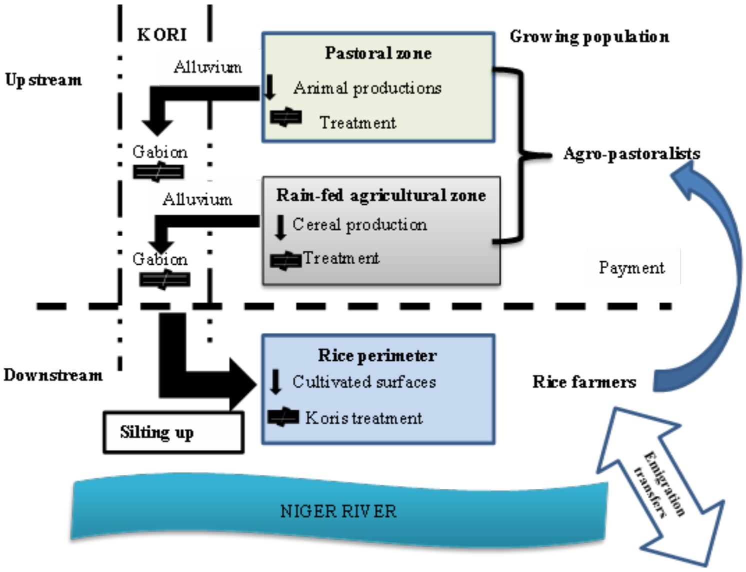

Figure 3 : Diagram of a transversal watershed of the Niger River

III. Results

Resources evolution

The main productive resources have experienced contrasting developments. Almost the entire irrigated perimeter is cultivated in irrigation. The total area exploited in irrigation is stable during the first 30 years before starting to decrease gradually and slowly. Some suitable plots for rice growing and fodder production are gradually reconverted and abandoned for rain-fed cereals production. The model leaves a small part fallow during the dry season campaign. It produces fodder and cereals on a few hectares during the winter season campaign. It leaves the plateau land fallow.

The population decreases slightly from the first year to the 65th year before stabilizing thereafter (figure 4). Part of the population is permanently emigrating to other regions where the workforce is better paid and they have lost their rice plots, which were their only sources of income. The other part of the population is not emigrating because they have diversified their sources of income by developing activities such as sedentary livestock and off-season crops, which are quite profitable.

Unlike humans, livestock numbers increase during the first years of the simulation before stabilizing towards the end. Intensive and transhumant livestock farming develops timidly. On the other hand, sedentary livestock farming develops rapidly and becomes more and more profitable over time. It is also complementary to rice growing, the residues of which constitute an important stock for feeding animals and their peaks of work are observed at different times.

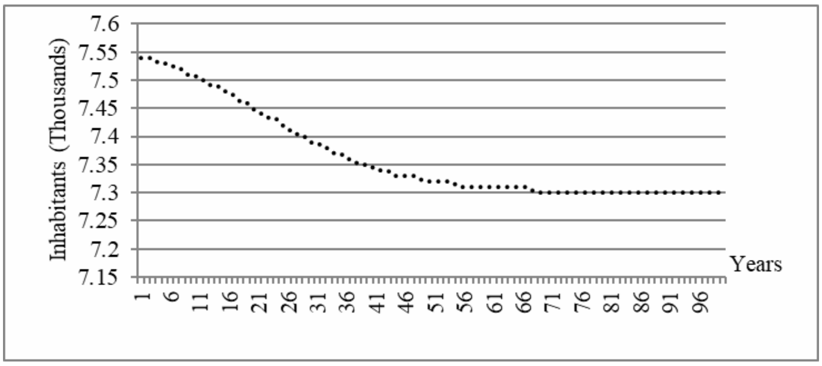

Figure 4 : People evolution

Income evolution

Three main sources of income were analyzed in this model. These are income from rice farming, livestock farming and migration. The overall monetary income of the basin increases until the 75th year because the income from animal production which increases until the 80th year. Livestock farming gradually replaces rice farming, the production costs of which become increasingly heavy. It has also made it possible to offer jobs to able-bodied workers and thus reduced migratory flows. The overall income stabilizes towards the end of the simulation when livestock farming no longer develops. At the same time, rice farming income decreases slightly during the first forty years. This decrease becomes more pronounced towards the end of the simulation when production costs and the need for funds to reduce erosion become significant. Migration income is initially stable, and then decreases slightly towards the end of the simulation. Livestock farming income is initially lower than that from migration and rice farming. It then becomes successively higher than the income from migration and rice farming (figure 5). Indeed, sedentary livestock farming has become very profitable and people are investing more in this activity.

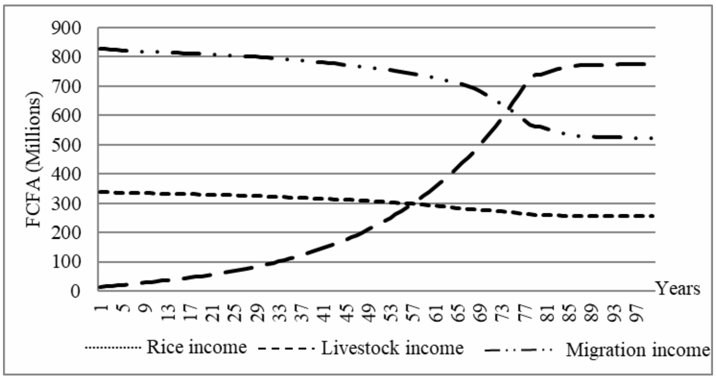

Figure 5 : Activities incomes evolution

Erosion management

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 (numbers and fodder resources). These agricultural practices are source of erosion which destroys the performance of the potential productive of the upstream lands. The consequences of poor agricultural practices combined with those of bare glacis and koris have accelerated upstream erosion. These negatives externalities are more accentuated at downstream in the irrigated perimeters because of the deposits of alluvium and the recurrent flooding of the crops. They will lead to losses of cultivated plots in the irrigated area. If actions are not taken, the model predicts total degradation of the irrigated perimeter after 30 years of operation if no anti-erosion development is carried out to significantly and sustainably reduce erosion damage, particularly alluvial deposits and flooding of cultivated plots.

To control this externality, the model chooses to implement some beneficial and supportable soils and water conservation practices in the upstream fields. Despite free adoption of some goods practices in fields by upstream producers, erosion remains high despite the implementation of less erosive cultivation practices in cultivated fields. This is due to the high siltation areas like koris and glacis, whose are not treated. However, the model adopts anti-erosion structures in upstream land, notably koris and glacis to preserves the downstream resources notably the irrigated perimeter if their treatment is financed. It adopts soils and water conservation techniques in the glacis and treats the koris if these techniques are financed or subsidized. With external funds, it carries out soils and water conservation technique in the parts not treated by upstream users because these investments are not beneficial for agro pastoral activities. It would be necessary to subsidize the implementation of soils and water conservation techniques in the unexploited areas in order to hope for sustainability of irrigated infrastructures.

Indirect tax for watershed treatment

The model with rice taxation predicts economic viability of rice farming activity while supporting the funds for the implementation of soil and water conservation techniques at upstream of the watershed and increasing the sustainability of natural resource management. The model suggests taxing a relatively high rate of 30,000 FCFA per hectare per campaign for the first year. It then imposes a constant tax of 13,000 FCFA per hectare per agricultural campaign. The model adopts a logical procedure with the theory of sustainability and efficiency of works to carry out and maintain soil and water conservation techniques. It first taxes the costs of installing new anti-erosion works and then the costs of maintaining anti-erosion works already carried out. The model's predictions are interesting. The perception of the predicted rate of the anti-erosion tax does not affect the viability of rice farming activities. These costs represent only a small proportion of the profits generated by rice farming activity and the environmental benefits generated by these investments.

Figure 6 may be interesting to calculate the payment rate for anti-erosion services. The intersection of the physical damage curves and damage without subsidies could correspond to an equilibrium point corresponding to an amount tax. If the tax rate is lower than the amount corresponding to this point, the irrigated perimeter would be degraded. And if the tax rate is higher than this amount, the irrigated perimeter would be preserved. This point does not determine the sustainability period but it allows us to create a correspondence between the physical damage of the irrigated perimeter and the monetary costs of the damage.

A relatively low subsidy is sufficient to increase the sustainability of the irrigated perimeter by a few years. A subsidy of 12,500 FCFA/ha/season is sufficient to increase the sustainability of the irrigated perimeter by more than 40 years. The sustainability of the resources of the irrigated perimeter depends on the choice of rice farmers. These analyses clearly show that erosion in a transversal watershed can be controlled by providing a fixed fund per farmer for the construction of anti-erosion structures. Thus, a payment system for anti-erosion services against a subsidy could be set up if rice farmers agree to collect funds via the management structures. Sustainability depends on the financing effort of rice farmers. If rice farmers provide subsidies, the degradation of the irrigated area is delayed by a few years. The sustainability of the irrigated area depends on the level of financing offered by rice farmers. If they provide an amount less than 20 million FCFA, the irrigated area deteriorates within ten years. If they donate more than 20 million FCFA, the sustainability of the exploitation of the resources of the irrigated area can be extended by several decades.

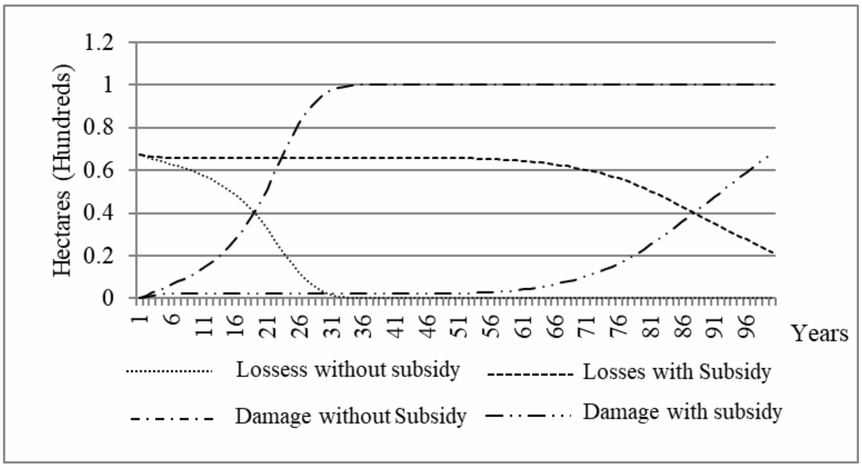

Figure 6 : Soil and Water Conservation Subsidy System

The sustainability of the irrigated perimeter and the benefits of environmental services increases proportionally to the amount of subsidies/payments. The higher the amount of payment, the more the sustainability of the permit and the environmental services increase.

IV. Discussion

The model predicts unsustainable exploitation of the irrigated perimeter without introduction of soil and water conservation techniques, due to silting up and flooding. The model predicts the degradation of the irrigated perimeter due to alluvial deposits and floods. These negative externalities are the consequences of poor agricultural practices upstream of the watershed in accordance with the work of the actors[5, 10]. This situation is also similar to the case of the Nakanbè basin in Burkina Faso described by[31].

The simulation results show the advantages of adopting certain soil and water conservation techniques. They do not completely stop erosion but it is possible to gradually slow it down and 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 said project. Several development actions and incentive policies, such as "food for Work", and "Cash for Work" have been successfully initiated as part of soils and water conservation technique, 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.

The model predicts the economic feasibility of financing a payment system for the development of a transverse watershed overlooking an irrigated perimeter to preserve it. A low flat-rate tax is sufficient to increase the sustainability of the exploitation of the resources of the irrigated perimeter. These results corroborate those of Chichilnisky [32, 33] who had shown that when the prices of environmental assets are high, the rates of resource extraction are low and hardly exceed the level of the optimal allocation from an economic point of view. Sustainability is also a function of the amount offered as subsidies or incentives to carry out practices. If the amount of compensatory payment is higher, the results will be extraordinary. The efficiency and positive impact of the implementation of anti-erosion techniques will be effective and sustainable when large subsidies are made to back up the efforts of users adopting the techniques in their area. These results are consistent with the results of work carried out by Fanny[34], Wuber[35] on the efficiency of payment systems in environmental services.

V. Conclusion

These simulations showed that it is possible to set up a payment mechanism for environmental services at the local level, between the upstream agro-pastoralists and the downstream rice farmers. The agro-pastoralists can adopt anti-erosion practices in the cultivated plots because they are beneficial for their activities. On the other hand, they will only carry out anti-erosion techniques in the non-cultivable parts in exchange for salary payment. The treatment of these parts does not bring them any profit. On the other hand, the rice farmers, beneficiaries of the treatment of uncultivated land, must collect funds to finance the implementation of anti-erosion developments upstream.

Rice farmers must pay the costs of implementing soil and water conservation techniques if they wish to preserve the resources of their irrigated area. If they wish to increase the sustainability of the irrigated area by about twenty years, they must collect funds of up to 20 million per year. And if they wish to preserve the resources of their irrigated area for longer, they must tax more than 15,000 FCFA per rice farmer per year. But, if they do nothing to reduce erosion, their irrigated area will disappear completely after about fifteen years of operation. 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.

The establishment of a PES mechanism is theoretically possible at the basin level. This work is far from exhaustive but it has allowed to initiate discussions on the management of erosive externalities in a transversal watershed, involving several actors with multiple and different objectives. Improvements are to be considered by including other parameters such as transaction costs, control costs and institutional costs relating to the implementation of payment for environmental service. Future investigations must focus on the analyses of the issues of usage rules and negotiations between upstream and downstream users.

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