Successive Dams for Sediment Retention in Hydrographic Microbasins in Ceará Semiarid Region[1]

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Abstract

Ceará natural resource base is very weak and highly susceptible to environmental degradation. To make things worse, it is located in the region most sensitive to climate instabilities that periodically impact Northeastern Brazil. Physical base susceptible to environmental degradation, indiscriminate use of soils and effects of inclement weather jointly contribute to accelerate the soil erosion process.

Erosion reduces soil capacity to ensure physical-chemical conditions required for crops, what in turn reduces the general population's income and generates poverty. To stop erosion effects, cultivation techniques and edaphic techniques are adopted, such as terraces and surrounding stone barriers. However, areas that fail to adopt such techniques contribute to transportation of sediments that are ultimately deposited in reservoirs. Ceará Secretariat of Water Resources has used the successive dam technique to retain such sediments.

Sediment retaining successive dam technique consists of a structure made of loose stones carefully disposed in the form of a Roman arch in a lying position in the hydrographic microbasin drainage pattern, aimed to retain sediments generated from erosion processes in cultivated areas and areas prepared for other purposes, such as road construction, etc.

Successive stone dam technique was tested together with other techniques in Hydroenvironmental Development Program (PRODHAM) areas, in Ceará municipalities of Canindé, Aratuba, Pacoti/Palmácia and Paramoti, where 3,332 successive dams were constructed in the period of 2001 to 2009.

Fundação Cearense de Meteorologia e Recursos Hídricos (FUNCEME) made some experiments in Canindé area and obtained average values for eight microdams with capacity to accumulate 8.37m³ of sediments over an average surface area of 45.6m³. In such basins, the reappearance of water springs, wildlife and productive activities was noted.

Key words: semiarid region; Ceará; hydroenvironmental; hydrographic basin; successive stone dam; sediments.

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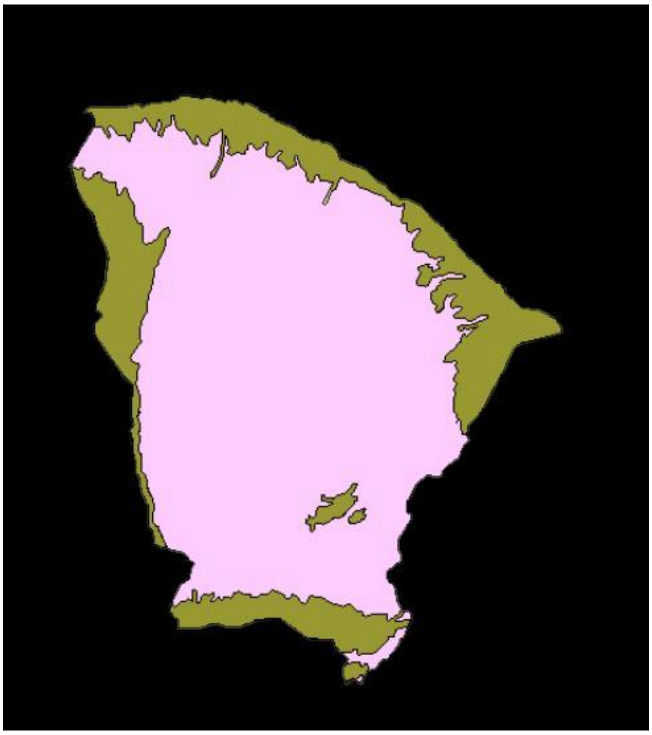
1. INTRODUCTION

Ceará is located in the region most sensitive to climate instabilities that periodically impact Northeastern Brazil. In addition to its vulnerability to temporal-spatial drought effects, most of the State's territory (Figure 1) has a peculiar physical base, including shallow, stony, and sometimes saline soils. Such soils, when used for "European-style" agricultural activities that include total deforestation, become much more vulnerable to degradation caused by erosion.



Source: SRH-CE/COINF.

Figure 1. The State of Ceará and its geological configuration. Crystalline basement is located in central area, while sediments (State edges) are located in all other areas.

Notwithstanding the state territory is subject to periodic droughts, upon the occurrence of a rainy period ("winter") the effect of such rain on the soil is quite strong, as the State is located in an equatorial region subject to heavy rains. In general, in can be said that water erosion and indiscriminate vegetative cover clearing are the two major problems associated with the quality of hydroenvironmental resources in the State of. As this is a State where rural economy depends heavily on the agricultural sector, perpetuating such problems means to accept the gradual soil impoverishment and river and reservoir sanding-up, with serious negative impacts on the rural population. With respect to the topic at issue, the agronomist engineer Guimarães Duque, in his book "*Solo e Água no Polígono das Secas*" (DUQUE, 1973), points outs that:

> "The system has led to uncontrolled erosion and soil denudation, by breaking the natural equilibrium between soil, flora, water, fauna and man's economic life. Man's devastation of native vegetation brings countless harmful consequences when rational methods are not used to keep the harmonious equilibrium of climate, soil, vegetation, water and animal forces".

In addition to impacts on vegetation, soil fertility and topography, erosion is also responsible for the increased wind speed, rain intensity and increased local temperature. These climate agents in semiarid region are quite unfavorable to the maintenance of soil quality (fertility, texture and depth).

In summer, naked land, evaporation and constant wind promote soil erosion by wind. In winter, harmful flood effect starting with the first rains faces a dry vegetation and a nearly-naked soil. Effectively, semiarid region soils are subject to erosion throughout the twelve months of the year.

Over the last decades, experts and governmental institutions have mechanisms to mitigate environmental degradation effects in Northeastern Brazil's semiarid region, in particular soil erosion. Among the most frequently adopted practices, the construction of successive dams for sediment retention stands out. In that effort, the two most important experiments were made in Pernambuco under the leadership of engineer José Artur Padilha, and in Ceará, by the Secretariat of Water Resources, when more than 60,000 dams were constructed during 1998-1999 drought under the Hydroenvironmental Development Program, and 3,332 sediment retaining dams were constructed through the application of greater technical rigor and the involvement of countrymen, during 2001-2009, in four selected hydrographic microbasins.

Pernambuco experiment took place in the municipality of Afogados da Ingazeira. There, successive stone dam technology was called "Zero Base", which consists of damming the caves by disposing the stones in the form of Roman arches, without any mortar or structural foundations. Such dams linked to one another over distances that depend on soil declivity, make sediments accumulate upstream to the Roman arch and create microclimates that ultimately increase biological diversity by maintaining the microbasin moisture for longer periods. As such, in 1966 that mechanism resulted in a

> "dynamization of water supply availability obtained from the implantation of interlinked dams and simple gravitational water catchment systems, conveyance networks, intermediate storage and distribution, and a consequent improvement in animal feeding management" (PADILHA, 1998).

Since then, that technology has been disseminated in Northeastern Brazil and adopted during drought periods in public works for implantation in intermittent steams, with the objective of improving soil and climate conditions in semiarid region.

Recently, in 1999, the Secretariat of Water Resources of the State of Ceará, with the objective of developing integrated technologies that would allow sediment accumulation in reservoirs, rivers and streams to be reduced, designed the Hydroenvironmental Development Project (PRODHAM) and included in its components a system called "Successive Dams". A brief description of successive dams for sediment retention and the experience adopted by PRODHAM based on Ceará (2001) and Oliveira; Alves; França (2010) works is provided below.

2. HYDROGRAPHIC MICROBASIN

Microbasin is a natural landscape where rainwater converges to a single site: river, stream or reservoir. As a planning and rural space occupation unit, hydrographic microbasin has been adopted as a practical alternative for results that are more consistent with a vision of a single cohesive world. The joint efforts by the population, community and governmental bodies are a basic requirement for the achievement of expected benefits under a sustainable development project.

By looking at a more extensive areas, preferably in rural environmental, one can note that there are higher places from which water flows down to a creek or stream until discharging into a river, stream or reservoir. Such higher places constitute the "water line", while the whole area where water is concentrated constitutes the microbasin.

In general, environmental, economic and social factors prevalent in such areas are somewhat homogeneous. This way, the development of plans for use and management, monitoring and evaluation of human activities in such microbasins is more effective when it relies on the involvement of local communities. Therefore, the whole geographic region, either inhabited or not, is located in a microbasin.

Microbasin, as a systemic unit, allows the interrelation of several factors involved in local production and occupation process to be identified to make human activities consistent with environmental preservation.

This way, promoting actions for integrated, sustainable rural development where the hydrographic microbasin is the planning unit, and the producer organization is the action strategy, is the best work process to obtain gains of productivity and use of adequate technologies from environmental, economic and social standpoint (OLIVEIRA, 1999).

3. STEPS FOR ACTION DEVELOPMENT IN A MICROBASIN

In a hydrographic basin, actions are developed to promote a harmonious coexistence between natural resource preservation and human survival conditions. For that, it is necessary that some actions are taken to involve the government and the population, among which the following sand out:

a) Capacity building of technical staff and farmers for hydrographic basin planning and soil and water preservation;

b) diffusion of soil management and preservation technologies;

c) introduction of soil cover and direct cultivation practices;

d) organic agriculture and agrosilvopastoral practices;

e) implantation of plant nurseries;

f) recovery of ciliary forest and degraded areas;

g) practices for water resource preservation and sustainable use;

h) adequacy of vicinal ways;

i) agricultural soil correction;

j) erosion restraining and control practices;

k) demarcation of contour lines and construction of terracing and stone barrier systems;

l) implantation of projects indicative of integrated microbasin management;

m) production and diffusion of technical and educational material; and

n) environmental education in schools and communities.

4. HYDROENVIRONMENTAL TECHNOLOGY PRACTICE THROUGH SUCCESSIVE STONE DAMS

4.1. Definition

Stone dams, also known as "successive dams" are constructed in the format of a lying Roman arch and loose stones disposed in 'wedge' style in tributaries (streams) classified in the 5th hierarchy order and above in the hydrographic basin. Visual details of the dam can be seen in Figure 2.

Source: PRODHAM.

Figure 2 – Air view of two successive stone dams in Canindé-Ceará.

However, to perform the tasks required by such simple and small works, compliance with some technical parameters is recommended, which even without requiring millimetric accuracy, will help to find the best way to construct such dams.

4.2. Purpose

With respect to hydroenvironmental aspect, the great importance of stone dam lies on the reduction of damages from inadequate methods for soil selection and use in hydrographic microbasins. Therefore, it is critical to adopt technological hydroenvironmental innovations, in particular in microbasins, where land tenure structure is heterogeneous and degraded areas prevail.

Introducing an ecodevelopmental and conservational culture is highly importance. From this view, natural resource exploration and preservation, especially those related to rational soil use in Ceará semiarid region, are key factors for degradation reduction in rural environment.

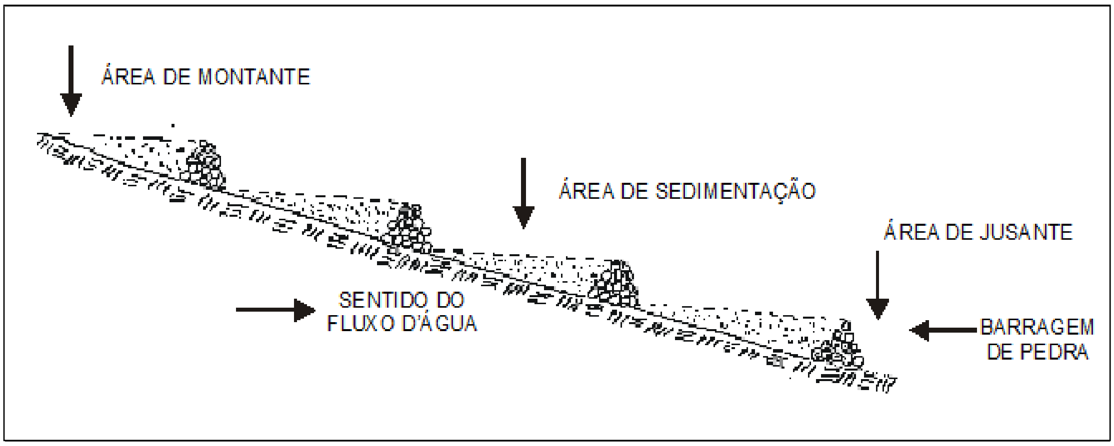
Implementation of successive stone dams aims, among other things, to:

- Prevent sanding-up and/or gradual sedimentation in microbasin riverbeds and reservoirs;
- promote the improved water quality in microbasin tributaries and reservoirs;
- promote the resurgence of several forms of vegetal (ciliary forest) and animal life;
- increase water availability in microbasin soil;
- provide was availability for animal consumption, according to a satisfactory temporal and spatial distribution;
- enable diversified agricultural and livestock exploration in sedimented terraces.

4.3. Selection of dam sites along stream channels

The stone dam construction stage that is most important and critical to allow the work to achieve its objectives is the correct observance of trinomial: location, benchmarking and demarcation prior to starting the construction of work.

In any case, the selection of sites adequate to the construction of stone dams should meet some basic requirements. The most critical requirement is that the selected work sites will provide the minimum conditions for structure anchorage to the watercourse margins. In addition, each work site should be provided with adequate material (stones) in sufficient quantity to meet the construction needs.
After the tributary (stream) selection in the microbasin, the construction operation should always take place from downstream to upstream (Figure 3) of water flow.



Source: Padilha (1997).
Figure 3 – Stone dam sequence.

4.4. Sanding-up and/or sedimentation time

Time for a sedimentation process to occur will depend on precipitation conditions in work site, especially with respect to rain volume and frequency and soil use conditions upstream to dams. Reappearance of herbaceous and arborous vegetation will depend on local edaphoclimatic conditions, and on anthropic action in the region.

Source: PRODHAM.
Figure 4 - Silted-up dam overflow in a sub-humid area of Pesqueiro River Basin in Aratuba-CE.

According to COSTA (2010),

> “volume of sediments retained by microdams is expressive. By taking BA03 microdam in Bananeiras stream in Cangati River microbasin in Canindé-CE as a reference, a volume of 3.249 m³ accumulated in the period of January to June 2002 over an area of approximately 24 m². Fundação Cearense de Meteorologia e Recursos Hídricos (FUNCEME), in turn, repeated that experiment in 2007 and 2008, and obtained average values of 8.37 m³ for eight microdams of 8,37 m³, over an average area of 45.6m². Proximity of values and consistency of results strengthen the importance and need of replication of this hydroenvironmental practice in the whole semiarid region.”

Source: PRODHAM.

Figure 5 – Dam silted up by more than 1.10 m over the period of 8 years in Cangati River dry area in Canindé-CE.

Source: PRODHAM.

Figure 6 – Effect of sediment retention and reappearance of arborous and herbaceous vegetation after winter period.

5. CONSTITUTION OF FIELD STAFF AND RECOMMENDATIONS FOR WORK CONSTRUCTION

5.1. Mobilization of work team

At stone dam construction stage, after work plotting, planning the use of labor is necessary, taking into account the following aspects:

- Before the construction of work, the construction team should have been preliminarily organized;
- at all works, each team should be divided into stone block arrangers and carriers;
- it is necessary to know in advance all means available for construction;
- it is estimated that between 12 and 24 workers will be necessary for each work;
- work should only start when stone deposits to supply the construction have been identified;
- it is important to check whether vicinal roads parallel and adjacent to watercourses are already available before the start of works;
- the several stages of works should be explained to all team members;
- care to be taken with workers' physical integrity, construction material handling, material organization, use of tools and equipment, etc., should be explained.

5.2. Tools required for construction

At the beginning of works, each team should be informed of instruments, demarcation material, tools and equipment that will be used in execution of works, as listed below:

- Sickles to cut sticks and stakes used for the construction of “stretchers” or “banguês”, or individually for work demarcation.
- Iron levers with a diameter of 3 cm and length of 1.80 m, being one lever for every five workers.
- One or two 5-km hammers in cases where stones need to be fractioned to make transportation and handling easier.
- Some shovels, pickaxes and hoes.
- Some auxiliary components, such as: transparent 20 and 50-m long level hose with diameter of 8 mm, similar to that used by masons, 2-m measuring tape, hammer for several uses, and a nylon thread bobbin.
- Leather gloves required for workers. Given the circumstances of work, they are indispensable.
- When conditions shall allow, carts or wagons should be used as an auxiliary material transportation equipment.

6. PRODHAM EXPERIENCE WITH STONE DAMS

In hydrographic microbasins of Cangati River (Canindé), Pesqueiro stream (Aratuba), Salgado/Oiticica streams (Pacoti/Palmácia) and Batoque River (Paramoti) 3,332 successive dams were constructed to retain sediments during the period of 2001-2009.

PRODHAM trained 400 farmers in construction of hydroenvironmental and edaphic works, who are able to work in any semiarid region of Northeastern Brazil. As expected, populations that benefit directly of the program have increased their preservation awareness and spontaneously adopt and benefit of hydroenvironmental practices and new farming production methods induced by PRODHAM.

6.1. Socioeconomic and environmental effect

In Cangati River microbasin, for example, the emergence of water springs has been noted. In a most humid microbasin (Pesqueiro Fiber microbasin in Aratuba) small water sources that existent in the past have reappeared and resumed to flow due to the recovery provided by successive dams.
In a relatively short time and at a low cost successive dams have generated possibilities of economic exploration of areas that had been until then unused because of erosion processes occurred over the years.

Sedimentation, depending on the area where the microbasin is located, generates somewhat humid terraces that enable agroeconomic exploration, including the increase of hydroagricultural exploration period. All this means, therefore, the improvement of life conditions of population living in semiarid regions.

In Cangati River dams in Canindé, several agroeconomic activities have been identified. In addition to exploration of annual crops, such as maize and beans, other crops such as watermelon, papaya, manioc, sweet potato and rice have been cultivated.

Restrictions to the better exploration of successive stone dams in Cangati River dams were restricted to land structure, as most landed estates are very small and therefore do not enable the construction of an adequate number of dams to enhance that hydroenvironmental technology.

The other group of landowners, that is, those who own the largest areas, has not shown interest in implanting stone dams in their land. Most likely justifications for that attitude include: they do not live in Canindé, do not explore the land and have no interest in innovation.

PRODHAM action through successive dams, has allowed a portion of that area to be recovered, specifically in intermittent streams, which are currently recovered and humid. Changes to soil structure have also occurred with the gradual increase of agricultural productivity, surface runoff and soil loss reduction due to erosion reduction, reappearance of water sources and several flora and fauna species.

6.2. Main constraints faced

Main constraints faced by the implantation of such technologies in PRODHAM influence area included:

a) Need of capacity building of local communities for construction works. This is not necessarily a problem, but it is rather a step to achieve the target. That knowledge may be obtained from short training sessions, but it will require an extended social commitment.

b) Successive stone dams were only implanted in large scale after local technical studies.

c) Need of continuous constructive and complementary interventions after floods until full rock filling consolidation.

d) Man’s inability to absorb quickly the benefits of successive dam structural action.

e) Land reform characterized by very small properties – less than 10 ha – what makes the adoption of hydroenvironmental works fully unfeasible.

f) Absence of owners of larger landed estates, which generated a lack of interest in constructing such dams.

6.3. Suggestions for successive dam replication in other microbasins in Ceará semiarid regions

Given the highly modified natural semiarid region scenery due to inadequate anthropic activities, which caused the adverse effects of floods with serious consequences for soil structure and reduction of tillable surface layers, option for successive dam implantation in semiarid region was a way to retain part of soils carried by erosion and promote, at the same time, the revitalization of biodiversity and greater agricultural exploration productivity.

That technological option should be associated with the construction of stone barriers or terraces in tillable areas to retain sediments in the soil and prevent greater damages. Successive dams together with stone barriers and terraces are highly necessary, as sediment transported will always occur, although in smaller quantity, in soils used for agriculture.

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