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Small farm dams research project in the semi-arid northeastern region of Brazil

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Abstract The semi-arid northeastern region of Brazil has a unique natural character, which historically, demanded several scientific and political efforts in order to improve the living conditions for the population in this region. The most suitable use of water resources has been the subject of much research for several reasons. Small farm dams represent one of the main sources of water during the dry season in the semi-arid region of Brazil. To know these water sources the aim of the study and the project named DISPAB was more appropriate. Conservation conditions, maintenance and estimated volumes were the object of the survey, as well as social benefits brought by this source of water for the semi-arid population. The results showed that these small dams are an important source of water for the region. However, for the state water agency, the real magnitude of importance and risks provoked by them is still unknown. Through the results of the research, methodological parameters have been obtained to support licensing actions related to the available water resources in small watersheds in semi-arid regions.

Key words semi-arid; small dams; water management; Brazil

INTRODUCTION

The degree of development of the semi-arid region in northeast Brazil is lower than in other areas of the northeast. Historical factors and limited natural resources, with an emphasis on soil and water and also the affect of drought, have contributed to an economy in this area which is unable to organize itself effectively and sustainably (MIN, 2005). One of the main water sources are small dams spread in this area, which serve a scattered population.

Small dams primarily serve to ensure the water supply during the dry season, establishing a connection between two rainy seasons (Silans, 2004). The number of dams with water surface over 1000 m^2 is estimated at 70 000 in the northeast, being one of the most dense dam concentrations in the world (Cadier & Molle, 1992).

It is estimated that in the state of Paraiba the overall volume of small dams is approximately equal to that of large reservoirs monitored by the State Government. This major source of water is exploited without proper planning and guidance through the state organ responsible for managing the waters resources. This shows the need for a construction permit of small dams and a systematic mapping of water bodies as an essential tool of the water resources management.

This paper presents the initial work by the project DISPAB-SA for investigation of small-damming in semi-arid northeastern Brazil. The research project DISPAB-SA (2008–2011) consists of a multidisciplinary group from the Federal Universities of Paraiba, Rio Grande do Norte, Campina Grande and Ceará, together with the AESA Executive Water Management Agency of the State of Paraiba.

The study proposed by this project aims to achieve methodological parameters to support licensing actions in semi-arid regions, related to water resources available in small dams and small watersheds. This paper presents the methodology used and results obtained from surveys in the semi-arid region in the state of Paraiba. This research was used as a standard and applied in other semi-arid regions of northeastern Brazil.

Initially the context of the semi-arid region in various aspects and a particular case study will be presented, then the characteristics of this research, followed by its application in a pilot study basin. Finally, some considerations about the survey and its results will be pointed out.

CASE STUDY

The study area of the DISPAB project is the semi-arid northeastern region of Brazil. It is characterized primarily by the regime of the rainfall, defined by scarcity, irregularity and concentration of the rainfall. In the semi-arid region, the annual rainfall ranges from a minimum of 400 mm to a maximum of 800 mm a year, and in some cases, up to 1000 mm. The total area corresponds to 980 089 026 km^2, and is home to a population of 21 178 168 distributed in 1135 municipalities (MIN, 2005).

The small watershed of the public dam Sumé, located in the semi-arid region of Paraíba State, was selected for initial investigation, with an area of approximately 768 km^2 and a storage capacity of 45 000 000 m^3. The region lacks a policy for the installation of a basic infrastructure, especially for the management of water resources to satisfy their basic needs (Barbosa & Santos, 1998). Furthermore, it has a high density of small reservoirs and a rural population that makes use of them.

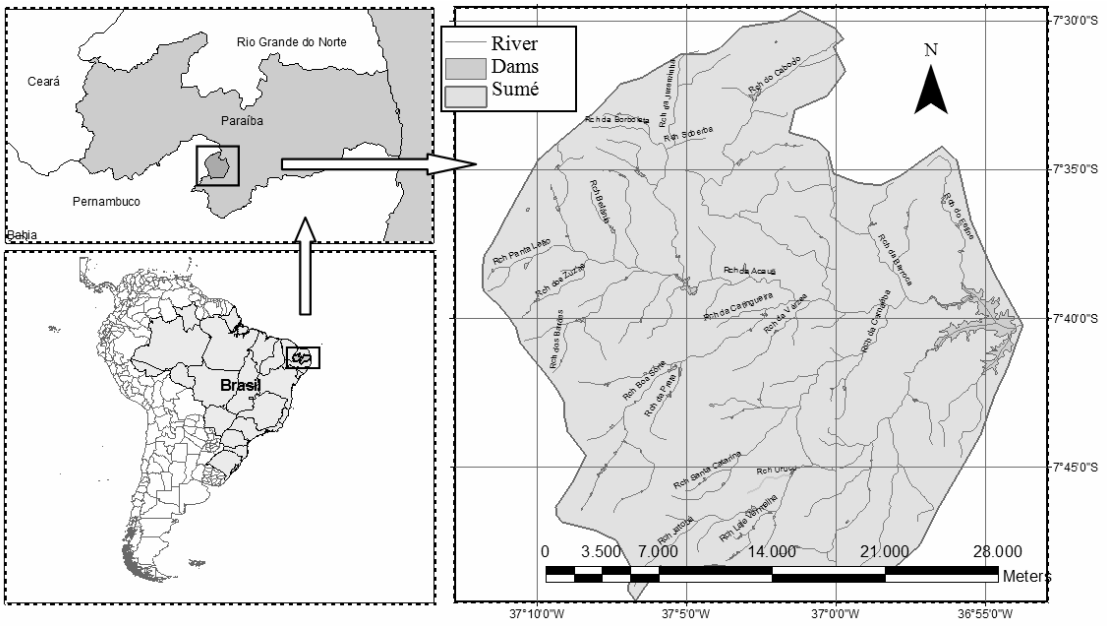

Fig. 1 Case study – Sumé watershed in northeast Brazil.

OBJECTIVE

The proposed study aims to get methodological parameters to support licensing actions in semi-arid regions, related to available water resources in small dams and small watersheds. In general, the project aims to understand the efficiency of small reservoirs with respect to one large reservoir.

In relation to small dams, the project aims to identify three important factors: their hydraulic efficiencies with respect to one large reservoir located downstream, the risk of dam break in times of floods, and their socio-economic efficiencies.

METHODOLOGY

The teams of the involved universities chose two research basins. Within the basins two pilot study basins were selected for the field work and application of the developed methodology.

To understand the impacts that small damming causes in the semi-arid region, it was necessary to adopt a wide-ranging approach.

The evaluation of hydraulic efficiency of small reservoirs and the impact on water availability of a large reservoir downstream began with an analysis of the existing water surfaces and the

estimation of the stored water volumes. To analyse the risk of breakdowns of dams the physical conservation status of the small dams and their spillways were reviewed as well as whether they were appropriately sized. And finally, to analyse the efficiency, socioeconomic interviews were held with their users, considering three beneficiaries: the owners of dams, the employees of the farms, and the diffuse population that lives in the neighbourhood.

Furthermore, as the basis for this work the "Small Dam Manual" (Cadier & Molle, 1992) was used as a reference to identify important issues to be raised through the surveys. This work is considered a work of great importance for the design and construction of small dams. It is a result of intensive field research on the habits of the population regarding the use of water in rural areas.

ANALYSIS OF WATER SURFACES BY SATELLITE IMAGES

In this study, the identification and extraction of areas of the dams were made by treating the image of satellite CBERS 2B (Camera HRC) and Landsat 5 (bands 3, 4 and 5) through the Geographical Information System Idrisi ® version 14.0. The images selected for this study were captured in May 2008, and corresponds to the rainy season in the basin under study when the dams had reached their maximum area of water surface. The analyses of satellite images allowed the detection of 631 dams in the Sumé basin, 98% of water bodies with an area less than 20 ha, indicating a high number of small dams in the basin.

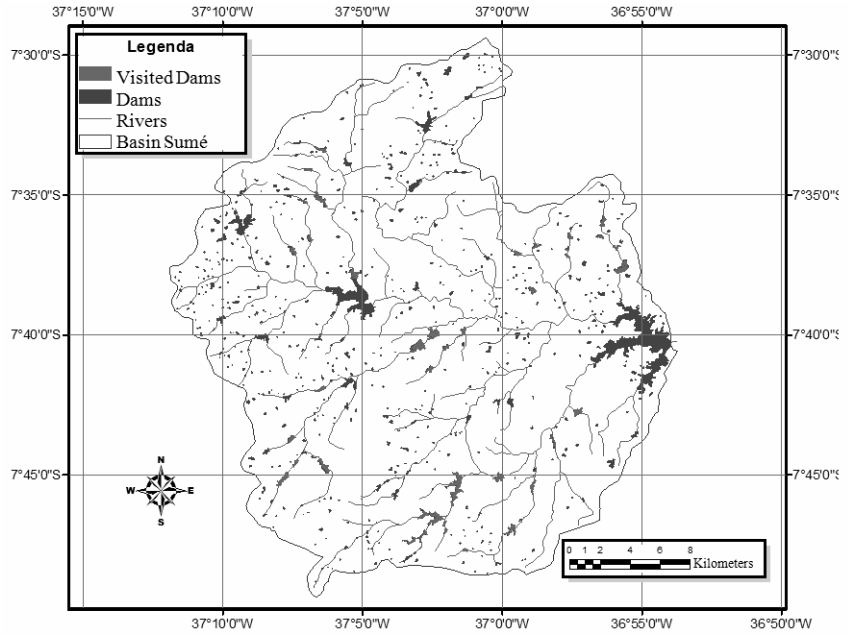

Fig. 2 Water surfaces in the basin.

FIELD ACTIVITIES

After the preparation of the surveys, the data were collected in the field soon after the rainy season, between 9 September 2008 and 16 September 2008. It is noteworthy that in 2008 the rainfall was above average in the region.

For the field study, information was collected from 42 of the 631 dams identified by satellite imagery in the basin with watershed areas ranging from 10 000 to 600 000 m^2 (Fig. 2). These dams were chosen by the following criteria: (a) watershed area, because the aim was to visit the greatest possible diversity of dams, (b) proximity between the dams to facilitate the work and preventing large displacements of the field teams, and (c) dams that were set along a river course.

During the field work, physical aspects of the dams were studied (delimitation of the water surface, length of the dam wall and spillway conservation, maximum depth of the dam), as well as social aspects related to the use of the reservoir water.

DETERMINATION OF DAM VOLUME FROM WATER SURFACES

Most dams do not have construction projects and their volumetric capacities are unknown. Because of the impossibility to carry out a bathymetric survey of all dams, we chose to estimate the volumes of the reservoirs by remote sensing according to Liebe (2002). The geometry of the reservoirs is related to physical variables in the region, such as topography, morphology, shape, streams, concavity or convexity of the valleys, and the shape of the water surface.

For dams with an area less than 20 hectares, François Molle found a correlation of 90.5% between volume, average slope of the stream and the reservoir area. The equation that expresses this relationship is given by:

$$V_x = 0.117 S_x^{1.263} \times DM^{0.49} \quad (1)$$

where V_x = maximum capacity of the dam; S_x = maximum area of the weir (S_x < 20 ha); DM = mean slope of main stream barred by the dam.

Equation (1) makes it impossible to estimate the volume of a particular dam with the precision required for a project, but is sufficient in terms of planning to review with accuracy the volumes stored in a region with an automatic compensation of errors (Molle, 1994). Consequently, for dams measuring less than 20 hectares, an amount equivalent to 98% of the water surfaces in the Sumé basin was chosen to apply the above equation. The volumes of the dams with an area exceeding 20 hectares were obtained from bathymetry during the field trip.

After the estimation of the volumes it was possible to observe a large concentration of reservoirs with volumes less than 10 000 m^3, this group of dams represents 60.73% of all reservoirs in the Sumé basin. However, considering the volumes retained by each reservoir, it is concluded that 31.63% of the retained volumes of the entire Sumé basin are in small reservoirs.

RISK EVALUATION OF DAM FAILURES

The risk evaluation of dam failures was made by field investigation on the maintenance of the dam and spillway and a comparison between the actual discharge capacity of the spillway and the discharge of the largest flood.

Field research

In the field trip it was observed that the dam walls are mostly composed of compacted clay and that all dams have spillways, and approximately half of these have other structural elements: guiding wall, spillway channel, groundsill and foundation. Most of the elements of a spillway are constructed of clay and concrete.

Regarding the maintenance of either the wall of the dam or the spillway, there are generally several problems. It was observed that virtually all small dams have infiltration downstream of the dam wall and, within that group, over 35% have large infiltrations. Ant nests were found in approximately half of the dams observed, as well as smaller armadillo burrows.

In addition, more than three quarters of the dam walls presented erosion, of which approximately 30.0% were in an advanced stage. In the case of vegetation on the dam wall, both upstream and downstream, only 12.2% of dams had adequate vegetation, in other cases, there were large trees or a total lack of protective vegetation.

Regarding the spillways, in 66.7% of the cases erosion was detected – rather mild or more severe – and almost half had some type of damage, usually on the groundsill and/or wall-guide.

The visited small dams are generally not in a good condition. This result was inconsistent with the information gained by interviews with the people who use the dams; 90% of the respondents

claimed to maintain the dams, but perhaps this is because the users of these dams have not maintained the dams properly. The poor state of repair of dams may compromise their integrity; this result is extremely disturbing. In the case of occurrence of floods, some dams could not resist and breached, causing possible human and material losses.

Assessment of flood discharge capacity

In addition to the 42 dams visited for surveys and on-site investigations, 33 small reservoirs were considered. These 33 dams were selected by size and location in the basin, so that the information obtained from the 75 dams studied can be spatially distributed over the entire Sumé basin.

The flood runoff was estimated according to the methodology proposed by Molle & Cadier (1992). It was calculated that the flood magnitude was expected to be exceeded by an average of one in 100 years; making these results comparable with the supportable discharge capacity of the dam spillways. The results show that over 80% of the spillways are under-dimensioned; an alarming number acknowledging the fact that over 40% of these are not capable of supporting 25% of the flood discharge.

Through this study it was confirmed that the vast majority of dams were built without the evaluation of the project in which both the dam wall and the spillway were measured by appropriate methods.

SOCIO-ECONOMIC STUDIES

In order to ascertain the socio-economic benefits of the dams, three surveys were developed regarding different groups of people related to it. Interviews were carried out with owners of dams, farm workers and the population spread around the region. An additional two surveys were also carried out on various aspects of the dams and one additionally for on-site investigation of the dam wall and its spillway.

Results of the surveys

Through interviews it was possible to identify that small dams are very important for most workers of the farms near the reservoirs. Nearly all of those interviewed said they did not work at another job besides working on a farm, and for most of them a dam is a factor of income. Nearly three quarters of workers reside on the farms where they work. It was found that most of the workers families have no other source of income besides the activities that depend on dams, indicating that they are an important factor to complement the income of workers and their families.

A very important observed fact is the interest of workers in staying in rural areas. Considering the low level of education of workers, many of them would probably have difficulties in migrating to urban centres. In addition, almost all said that the water available in the region is sufficient for the developed activities.

All investigated dams are utilized by their owners, although for less than half of them the dam is a factor of income and most families have another income, independent of the dam. Dam owners have an educational level which varies, most of them studied up to grade eight. About half the surveyed owners had more than two workers on the farm. Despite not having the dam as a factor of income, the vast majority did not lease the water from the dam. It is important to mention that according to these interviews, the dams have a greater degree of importance for workers than for their owners.

Much of the diffuse interviewed population uses water from small dams and does not practice other activities than work in the field; they also studied mostly until the first grade and normally have a large number of people in the family. Despite the interviewees using the water of the small dams, only about half of them considered the dams very important. All respondents said that the water available in the region is sufficient and most of these want to continue living in the rural area.

It was verified through the interviews that most of the users of small dams are unaware of their storage capacities, while approximately 100% are using these waters. Consulted people were

usually able to inform the time of construction of the dams; more than half were built more than 25 years ago.

The intensive livestock industry in the region demands the majority of the water in the dams, and animal watering uses over 80% of the water. The livestock mostly drinks directly from the reservoir. This indicates that the dam is not being properly used, because the animals with direct contact with the dam can contaminate the water, as well as cause the deterioration of the walls upstream and downstream.

Considering that approximately 20% of small dams studied are used for household chores such as cooking and drinking, these uses may be compromised if the water is contaminated by the livestock. The most required domestic activity is laundry (around 30%) and almost a third of this activity is performed directly in the dam water; this also pollutes the water and harms other uses.

According to those interviewed, most of the investigated dams do not dry out every year. These dams frequently have an overflow, while 20% of them have an annual water excess.

CONCLUSION

The methodology led to several observations of interest in the study of small dams. In the study area, small dams retain and store a considerable volume of water. Their structures are not in good physical condition and were not properly measured, allowing frequent flooding during rainy periods.

The results found are alarming, on both the physical and social aspects. Small dams have significant water storage volumes that could be properly utilized in this region with such rare water resources. Therefore, the state should put more effort into the proper use of this water source.

These small reservoirs provide benefits for the semi-arid population, making it one of the factors for the land workers to stay in rural areas.

Because of the diversity and extent of the northeastern Brazilian semi-arid region, other realities and facts can be observed in other regions, and so this study is being applied, using the model presented here, in five other basins. Furthermore, this methodology will be improved to better integrate the various types of information collected.

Knowing the peculiarities of small dams in the semi-arid region is a challenge; it is important to ensure that this water resource is properly utilized and planned for by the water management agencies. With this well-stated knowledge, there is a possibility of bringing this information to people who really need it, i.e. the population that benefits from these dams.

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