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PRODHAM and Geoenvironmental Study in Cangati River Microbasin in Canindé-Ceará

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Abstract

In conformity with the Hydroenvironmental Development Project – PRODHAM focused on semiarid region sustainability through soil, water and vegetation conservational actions in hydrographic microbasins, where man is the focal point, Fundação Cearense de Meteorologia e Recursos Hídricos (Ceará Meteorology and Water Resource Foundation) – Funceme performed the Geoenvironmental Study in Cangati River Basin (pilot area of 75.65 km^2), in the municipality of Canindé – Ceará, partially financed by the World Bank.

Biophysical monitoring studies (performed by the technical staff of Funceme Water Resource Department) only were possible thanks to the implantation of a physical infrastructure and diagnosis of geoenvironmental aspects of that microbasin.

Collected data on hydrogeological and environmental variables were sufficient to show the scope and characterization of hydroenvironmental behavior of microbasin studied, by providing knowledge and information important for risk control and management in semiarid region, and consequently for the improvement of geoenvironmental conditions and related population's life quality.

Generated data were therefore an input for: studies of estimated water potentialities; quantification of surface runoff; understanding of transportation dynamics; sediment accumulation in successive dams; understanding of water quality; ciliary forest recovery; reduction of sanding-up process in reservoirs; increase of soil moisture; increase of productivity related to dray land agriculture; and population's awareness of sustainable use and preservation of natural resources.

Studies have also contributed to the generation of technical-scientific works; post-graduation researches; as well as to capacity building and training of middle-level technical staff and local community members.

Key words: water resources, water, soil, vegetation, microbasin.

1 Introduction

Subproject for Geoenvironmental Study of Cangati River Microbasin in Canindé-CE (Pilot Area) implanted by Fundação Cearense de Meteorologia e Recursos Hídricos – Funceme, funded by the Hydroenvironmental Development Project (PRODHAM), partially financed by the World Bank, started on August 01, 2007 and its final report was completed in August 2009.

The surveyed microbasin covers a surface area of 75.65 km^2, located in the Northeastern portion of the State of Ceará.

Monitoring studies on water, oil and vegetation were performed by the technical staff of Funceme Water Resource and Environment Department.

2 Significance of subproject

The search for adequate instruments and/or technologies to support the planning and management of environmental resources of small hydrographic basins is today a major concern of current governments. Studies and researches in that field of knowledge have been intensified all over the world.

In effect, monitoring the natural resources of a hydrographic basin constitutes a strategic activity leading to the creation of a data and information base that, if continuedly updated and disseminated, will guide the management of such resources, and support the decision making process and the formulation of guidelines and actions.

This way, the subproject, which is based on the implantation of a monitoring infrastructure adequate to the region, has supported the management of the microbasin natural resources to improve the local community’s life quality, thus justifying the funds allocated to its execution and stressing its importance.

It is also emphasized that, according to the strategy adopted by the survey for the production and diffusion of information, such studies have allowed technical-scientific and post-graduate works to be generated by researchers.

3 Characterization of study area

3.1 Location and Access

Cangati River microbasin is located in the municipality of Canindé, in the northeastern portion of the State of Ceará, between South Latitude parallels 04^{o}34’00” and 04^{0}42’00” and meridians 39^{o}21’00” and 39^{o}26’25” west of Greenwich Figure 1). From Fortaleza, access is made through BR-020 road to a distance of approximately 145 km.

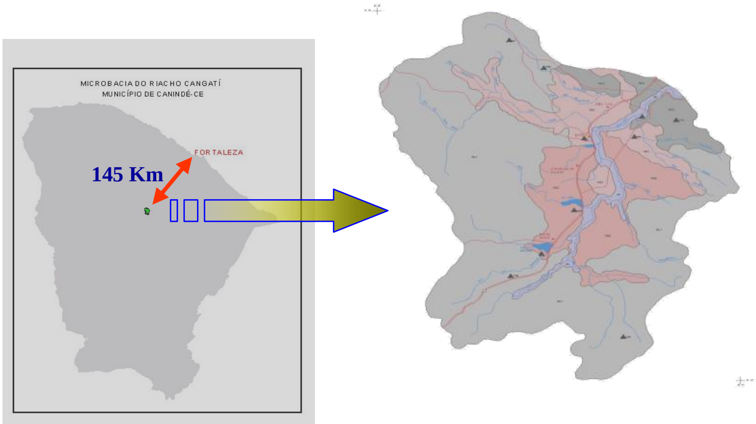

Figure 1: Location of study area

3.2 Geological aspects

Published works related to crystalline soils in Canindé region domain are all at regional level. Related units are included in a vast geological context comprising the Crystalline Basement (Precambrian) and non-consolidated material (represented by (1) alluviums and colluviums). At regional level, lithologic types defined according to BRITO NEVES (1975) - apud COSTA (2004), and NASCIMENTO *et al.* (1977) - apud COSTA (2004), alternate in micaschist, micaceous quartzite, paragneiss, migmatite and marble sequences. Also, dike intrusions comprising the (**2**) Upper Precambrian magmatic suite (questionable opinion) predominantly confined in (**3**) Itatita complex rocks occur. In microbasin (**4**) migmatites and gneisses of Northeast /Lower to Middle Precambrian Complex predominate and influence the basic composition of weathering cover and morphologic compartmentalization of local relief. The main geological structures in the region appear as faults predominantly toward NE-SW direction. In Canindé outskirts, the general direction of foliation, and consequently of such structures, changes toward NW-SE direction (Costa, op. cit.).

3.3 Geomorphologic aspects

Geomorphologic aspects shows the dynamic influence of current and past geological, paleoclimatic and morphodynamic factors occurring in the area along its geoenvironmental development., Morphogenetic processes predominate, as local climate conditions combined with the surface runoff regime, topography and vegetative cover represent the main denudation agents, in prejudice to chemical processes associated with more humid climates (Costa, op. cit).

Natural Domains occurring in the microbasin include: **(a) plains and fluvial terraces** – with small spatial dimensions, represented by falling tides and floodplains, plain and softly undulated relief COSTA (op cit.); **(b) backwoods depression** – marked by plain or slightly undulated topography, at average heights of 130 – 150 m. The surveyed region is a major characteristic sector of Backwoods Depression, which is defined as Peripheral Depression. Its most important characteristics include: (**1**) an accentuated lithologic diversification; (**2**) outstanding roles of physical weathering process and waste removal by diffuse and concentrated runoff; (**3**) indistinct elimination of lithologies and structures by erosion; (**4**) widespread brushwood cover, with eventual changes of appearance and flora due to climate and soil changes; and (**5**) small thickness of rock alteration cover (SOUZA, **1**988 apud COSTA, **2**00**4**); **(6) residual massifs** – represented by a topography ranging between 500 and 800-m high, which acts as a watershed for the hydrographic basin. In surveyed microbasin, relief is undulated and contains rounded hills cut by gullies (excavations, grooves) caused by rains, which form intermittent streams. Hill tops are flattened and slopes have a declivity around 4% (Costa, op. cit.).

3.4 Soil aspects

Understanding the soils constitutes one of the main bases for territorial planning works. For that, a semi-detailed survey and an evaluation of land use were made (FUNCEME 2001). With the objective of adjusting to the current Brazilian Soil Classification System (EMBRAPA, 2006), classes of soils identified have been renamed.

Heterogeneity of environmental characteristics to which Ceará is subject provides a vast soil variation. By analyzing the pedological context of the surveyed hydrographic microbasin, the prevalence of typical backwoods depression environments can be noted, which are characterized by an association of quite diversified soils that are typically shallow or moderately deep, with incidence of rock outcrops and detrital pavements layers. General characteristics of soil classes according to FUNCEME (op. cit.) are listed below, including the soil nomenclature according to EMBRAPA (1999) and the new corresponding classification (between brackets) according to EMBRAPA (2006).

<u>RED-YELLOW PODSOL / NON-CALCIC BROWN PODZOLIC SOIL (CHROMIC LUVISOL)</u>
This includes B-textural, non-hydromorphic, acid soils with low aluminum saturation and a high quantity of easily decomposable primary minerals, which constitute sources of plant nutrients. They also have medium-to high natural fertility (JACOMINE *et al.* (1973). They are typically well drained soils and have a medium to high agricultural potential, depending on water availability and relief conditions. In the microbasin, these soils are little deep.

<u>EUTROPHIC ALLUVIAL SOILS (LITHOLIC NEOSOLS)</u>
These comprise little developed, predominantly non-hydromorphic mineral soils from recent fluvial deposits, where only the surface A horizon is differentiated and followed by a succession of stratified layers that in general do not have a pedogenetic relation with one another (JACOMINE *et al.* op cit. These soils range from moderately deep to very deep and generally have high agricultural potentiality. They are located along rivers of surveyed microbasin.

EUTROPHIC ALLUVIAL SOILS (LITHOLIC NEOSOLS)
According to JACOMINE *et al.* (1973), these are poorly developed soils ranging between shallow and very shallow. Such soils may be eutrophic or distrophic and mostly display too many stones and rocks on the surface. They have moderate to accentuated drainage and are typically very susceptible to erosion. In the surveyed area, such soils display an eutrophic aspect with weak or moderate A-horizon and sandy or medium texture on a mountainous, strongly undulated and undulated relief.

3.5 Vegetative cover aspects

The State of Ceará has several types of vegetation, among which brushwood predominates. This is due to semiarid conditions, stony soil conditions, water shortage and to the fact that most of the State has altitudes below 500 m. Variations of such factors have a great importance for flora facies standards and distribution. The vegetation predominating in the microbasin is low brushwood (xerophyte), according to FERNANDES (2001) apud COSTA (2004), where species of shrubby appearance and physiology ranging between 2 and 4-m high predominate. Main species found in the area include: quince tree (*Croton sonderianus*), jurema preta *(Mimosa hostilis*), aroeira (*Astronium urundeuva*), pau branco (*Auxema onconcalyx*), and others.

3.6 Hydroclimatologic aspects

Climate:
Most of natural processes are influenced by climate. Topography, soil, vegetation, water resources, and especially the human life are adjusted to weather and climate conditions. Approximately 92% of Ceará surface area is influenced by a semiarid climate and extended drought periods. Ceará semiarid region occupies areas corresponding to subequatorial latitude, and therefore displays the following characteristics: **(a)** high temperatures all over the year; **(b)** low precipitation rates in general below 800 mm per year with spatial and temporal irregularities; **(c)** high evapotranspiration rates and small volume of water available for plant development; and **(d)** small capacity for water retention in soil.

According to Koppen’s classification, the surveyed microbasin may be included in BSw’h’ climate type (hot, semiarid climate).

In the municipality of Canindé, first rains occur in December-February. The intertropical convergence system (CIT) operates in that region at a lower intensity than in coastal and mountain areas, where it is influenced by trade winds and relief, respectively. Average temperature is 27^{o}C, maximum temperature nears 34^{o}C, and minimum temperature is around 22^{o}C. Annual precipitation is around 756.1 mm.

Water resources:
The study of hydrographic network of a particular region will allow the identification of water occurrence and availability, in addition to diagnosing the degradation conditions of neighboring areas in terms of production, transportation and sediment accumulation

(hydrosedimentological processes) in river beds and intermediate strips (slopes and watersheds).

The municipality of Canindé comprises Curu basin (78.4%), Metropolitan basin (19.2%), Acaraú basin (2.16%) and Banabuiú basin (0.23%). The main river in the microbasin is Cangati River, considered of 2^{nd} class in hydrographic hierarchy of Choró River, a component of Metropolitan Basin. There is a dendritic, overconcentrated drainage network of small temporary streams and brooks, which depend on pluviometric regime.

3.7 Aspects of land use and occupation

With respect to soil use and occupation, in the area of influence of PRODHAM in Iguaçu district agriculture dominated and remaining forests predominate. In Cangati River hydrographic microbasin land tenure status comprises six (06) institutional aspects: (**a) f**amily prop**e**rty; (**b**) heirs' land; (**c**) ownership land; (**d)** tenant's land; (e) partnership land; and (f) "others". Item "others" means practically leased land. There are 193 properties, as shown by Table 1.

It is noted that Iguaçu community has the highest number of landed estates, accounting for 31.61% of total.

Table 2 shows the types of land uses in microbasin communities. It is noted tat Cacimba de Baixo community has the highest number of land uses, accounting for 32.57% of total uses. It is also noted that São Luiz community shows the best land use balance, and the microbasin has a predominantly agricultural vocation.

Table 1: Landed estates per community and legal status

Community	**Family Property**	**Heir's land**	**Own land**	**Tenant' land**		**Partner-ship land**	**Others**	**Total**
				Partner ship	**Lease**			
Barra Nova	0	4	0	4	7	3	2	20
C. de Baixo	9	12	0	9	8	4	5	47
Iguaçu	8	35	0	0	5	3	10	61
Lages	0	3	0	10	10	1	0	24
São Luiz	10	17	0	5	2	1	6	41
Total	**27**	**71**	**0**	**28**	**32**	**12**	**23**	**193**

Source: FAHMA (2005-2008)

Table 2: Number of occurrences per type of current land use

Community	**Agriculture**	**Pasture**	**Fallow**	**Forest/ Refor.**	**Total**
Barra Nova	18	1	5	0	24
Iguaçu	45	10	13	10	78
Cacimba de Baixo	57	15	22	6	100
Lages	22	2	4	0	28
São Luiz	39	21	16	1	77
Total	**181**	**49**	**60**	**17**	**307**

Source: FAHMA (2005-2008)

3.8 Socioeconomic aspects

Cangati River microbasin has a population of 871 individuals distributed over 213 families. Its demographic density is 11.51 inhabitants per km^2. This average is lower than those of the municipality of Canindé and the State of Ceará (21.81 and 51.00 inhabitants per km2, respectively), according to IBGE data.

26.64% of total population are illiterate. Most population, that is, 43.05%, started but did not complete basic school.

There are five (05) associations in the microbasin, one in each community. They have 265 members. Families' income originate from 33 sources or activities. Main activities are agriculture and livestock.

In general, dwellings have more than one water supply source. Most usual are: cisterns, water holes, wells, reservoirs, and collective CAGEGE and Municipal systems.

Sewage disposal is quite deficient in most houses, and most usual means of transportations include bicycles, tamed animals and motorcycles, followed by motor cars, load carts or small carts and trucks, in smaller scale.

4 Water Resources

Hydrographic understanding is only possible by developing topographic, geological, climatic, socioeconomic, environmental and hydrological studies, preferably including the follow-up of physical conditions and potential future changes in the area.

Based on such aspects, Funceme designed and performed the survey by implanting a monitoring infrastructure adequate to the region to support the microbasin water resource management and improve the local community's life quality.

4.1 Surface water monitoring

Changes to soil occupation and use, anthropic factors and especially the intensified agricultural activity has caused environmental disturbances in Cangati River microbasin and impacted the water resources. It is then evident the importance of collecting hydrologic data to support the evaluation of consequences from interventions, such as the removal of native vegetative cover and construction of successive dams, among others. This way, the continued water monitoring and the collection of historical hydroenvironmental data constitute an essential instrument for a better evaluation of critical hydrologic phenomena occurred in that basin. This encouraged the generation of actions for better understanding of hydrologic process dynamics.

4.1.1 Microbasin instrumentalization

Flow measuring flumes and limnograph protection works:
Two flumes were constructed in Salgadinho and Gatos streams, respectively. Photo 1 shows one of flumes constructed together with the limnograph protection work.

Photo 1: Flow measuring flume and limnograph protection works

Also, 2 automatic stations (pluviometric & fluviometric) were also acquired and installed beside each flow measuring flume, as shown in Photo 2.

Photo 2: Installation, data collection and evaluation of equipment calibration

In addition, 2 limnimetric rulers were acquired and installed in flow measuring flumes to allow the accuracy of level sensor datalogger to be adjusted, as shown by Photo 3. Other 6 rulers were installed in 2 Cangati River sections for eater level reading.

Photo 3: Installation of limnimetric ruler in one of flow measuring flumes

Such rulers were also installed upstream and downstream of some successive dams (Photo 4) to monitor sediments accumulated in riverbeds.

Photo 4: Installation of limnimetric ruler in successive dams

4.1.2 Data collection

Works developed in this part of study referred to the collection of real data on physical hydrology parameters, especially those included in rain-discharge transformation process and quantification of sediment afflux to successive dams, among others.

<u>Climatologic:</u>
Data on air temperature, atmospheric pressure, relative air humidity, wind speed and direction, precipitation and total solar radiation were monitored throughout the survey period (14 months) by a meteorological station installed by Funceme in the area, which is responsible for collection and analysis of that information.

<u>Infiltration:</u>
Understanding that parameter is critical for the calibration of rain-discharge transformation models. As such, for direct determination of water infiltration capacity in the microbasin, infiltration essays were made in different points with the objective of obtaining the most similar conditions possible in each of them. It was also decided that, in addition to the type of concentric ring essay, a most adequate approach through “Beerkan” method should be made to include a greater number of tests for hydrodynamic soil characterization in terms of effective execution of works and spatial representativeness.

Skilled researchers report that using that method may advantageously replace the traditional concentric ring essay, especially in location of difficult access and restricted water collection. Photo 5 illustrates the infiltration essays by both methods referred to above.

Photo 5: Infiltration essays – concentric rings and "Beerkan"

<u>Fluviometric:</u>

Fluviometric data (level and discharge) necessary for the survey were obtained from data collection platforms (DCP) installed in the microbasin. Data recorded by those devices were compared to readings in limnimetric rulers installed in the site, which also served as level reference for flow measuring flume calibration. In such control sections, discharge curves were calibrated.

- ***Key curve calibration***

This activity relied on the logistic support of the firm Dimensão Engenharia Ltda. for field essays related to flow measurements for key curve calibration in monitoring sections (Photo 7).

Photo 7: Discharge measurement at key-curve calibration stage.

The locations of three measurement points established by Funceme were: in both flumes where data collection platforms were installed, and in Cangati River, as the main river of monitored microbasin. In those same locations, the field team made water collections to analyze the concentration of suspended solids.

- ***Water level measurement in flumes***

Water level reading in both rulers installed in flow measuring flumes was made on a daily basis, by recording the measurement and its date. Photo 8 shows the water level measurement in flume 1 built in Salgadinho stream.

Photo 8: Measurement of water level in Salgadinho stream flume.

<u>Water samples for physical-chemical and bacteriological determination:</u>
To characterize water quality in the microbasin, water samples were collected from reservoirs, rivers and streams in the period of September 2007 through December 2008 for physical-chemical and bacteriological analyses. Ten (10) collection points were selected in reservoirs, and six (6) in rivers and streams.

Regarding the sample collection procedure, the technique recommended by CETESB (1988) was adopted. Analysis methodology followed APHA recommendations (1998). Samples were processed in the laboratory of Fundação Núcleo de Tecnologia Industrial do Ceará – NUTEC.

Photo 9 shows the surface water collection points selected under the study.

Photo 9: Streams and reservoirs monitored in the microbasin

Sedimentometric:

Under the study, depth of sediments accumulated in riverbeds by successive dams, and sediments suspended in water were monitored, including the determination of their granulometry. Such parameters were critical, as they allowed the dynamics of sediment accumulation in microbasin area to be evaluated. Photo 10 shows the sequence of suspended sediment collection procedure, from the selection of stations along the river cross section to depth measurement and collection.

Photo 10: Sequence of collection procedure

4.1.3 Hydrochemistry of surface waters

Water samples were collected from reservoirs and streams for ion analysis to identify the main components of salts present in water, determine the water hydrochemical standards, and track their variations during both dry and rainy seasons.

Results of analyses were plotted into PIPER triangular diagrams, according to example in Figure 4. This information is highly important, as it allows inferences to be made on possible chemical reactions likely to occur in microbasin waters.

A great predominance of bicarbonated waters in the waters of that reservoir is noted.

Waters were also classified as to their use for irrigation according to classification proposed by the United States Salinity Laboratory (USSL).

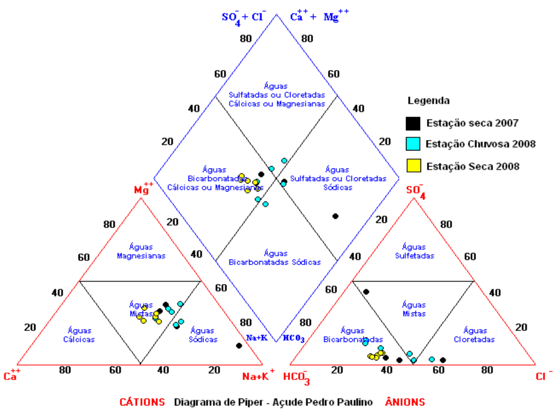

Figure 4: hydrochemistry of Pedro Paulino reservoir

In general, waters collected in 2008 showed a higher quality for irrigation than chose collected in 2007, possibly because of greater precipitation in 2008, which promoted a greater salt dilution and EC (electric conductivity) reduction.

4.2 Groundwater monitoring

Surveyed microbasin is within Undivided Precambrian crystalline rock domain. From hydrogeology standpoint, aquifers (fractured) constituted by such rocks are typically discontinuous and form restricted water storage and circulation domains, where water supplies frequently present salt content above the limits tolerated by man and animals. Groundwater exploration basically occurs in alluvial aquifers, which are of better quality.

In semiarid region, several techniques have been adopted, among which the construction of underground dams stands out, which increase water availability in that environment. Based on that experience, a specific approach plan was formulated for the study of alluvial aquifers in the microbasin, which places emphasis on underground dams constructed in that microbasin. Dimensional and hydraulic characterizations were performed in those areas. Potentiometric levels in those aquifers were monitored for one year, and water samples were periodically collected for physical-chemical analyses. Activities performed, treatment of collected data, and results of respective analyses are detailed below:

4.2.1 Staff mobilization and training

Hydrogeological studies included training the local community inhabitants in systematic monitoring of water levels (potentiometry) in selected alluviums. Reading was made by electric probes in piezometric and observations wells.

4.2.2 Preliminary works

Four alluvium sections associated with four underground dams constructed in Chicote (1), Salgadinho (1) and Felão (2), respectively were selected for studies.

Geometric and hydraulic characteristics of alluvium sections upstream to all underground dams were surveyed for characterization of hydrogeological potential of the alluvial aquifer associated with each dam.

- ***Geometric parameterization of alluvial sections surveyed***

Geometric parameterization of alluvial sections consisted of establishing the outline of such formations with the help of DGPS, and making drillings along alluvial bodies until the point where thickness allowed such their characterization as an aquifer. Their cross section width and sediment characterization were also determined.

Material extracted from bore was analyzed and described in terms of: depth, granulometry, occurrence of fine or coarse material, color, moisture content and, whenever possible, likely composition and alteration material. Photo 11 shows some of stages involved in drillings.

Photo 11: Auger drilling stages in one of underground dams

- ***Hydraulic parameterization of alluvial sections surveyed***

Concomitantly with works for geometric characterization of alluvial sections, field essays were performed for hydraulic parameterization of such alluviums. In sections where auger drillings were made, essays to estimate the hydraulic conductivity of alluvial environment were also performed. To obtain a sampling standardization, it was decided that sampling would be made at the same depth (1 m). Pourche method, also known as "inverted well method" was adopted, which is used for soils without water table.

4.2.3 Potentiometric level monitoring

Groundwater monitoring in selected alluvial sections was made in February-November 2008. Before that, it was not possible to read the water levels in piezometers and wells because they were dry. Data were obtained with the help of an electronic level meter and measuring tape. Monitored points were located in piezometers, upstream and downstream of each underground dam, and in their observation wells.

4.2.4 Monitoring of groundwater physical-chemical characteristics

To characterize water quality in the microbasin, water samples were collected from selected wells in alluvial bodies on a monthly basis in the period of September 2007 through December 2008 for physical-chemical and bacteriological analyses. Collection procedures, methodology and analysis were the same adopted for surface waters. Readouts and other information were recorded in field sheets.

4.2.5 Hydrochemistry of groundwater

To identify the presence of components of salts occurring in waters, highest concentrations of ions were determined and expressed in mg/L. Some widely recognized analysis and classification techniques were applied, including Piper Diagram.

- ***Hydrochemical classification of waters by Piper Diagram***

This classification was used to evaluate especially the temporal groundwater behavior for a further analysis using the recharge standard of alluvial aquifers. Figure 6 illustrates the hydrochemical behavior of Felão II stream underground dam, the waters of which are predominantly chlorinated and mixed bicarbonated.

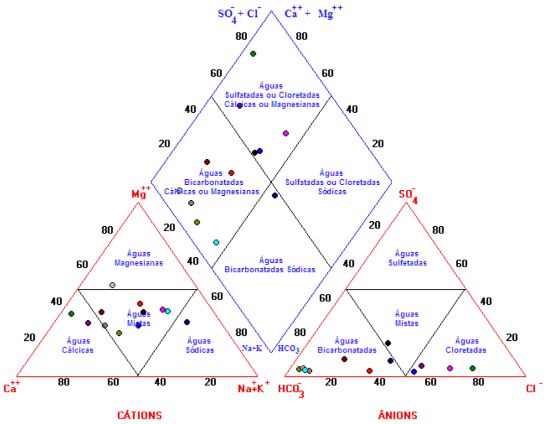

Figure 6: Hydrochemistry of Felão II underground dam

- ***Classification according to total dissolved solids (TDS)***

Based on TDS estimated by Electrical Conductivity, groundwater was classified for salinity, ranging between fresh and brackish, where the latter predominated.

- ***Classification of irrigation waters***

To determine the level of restriction to use of such waters, their classification was made according to USLL (United States Salinity Laboratory), based on Sodium Absorption Ratio (RAS), which is an indicator of risk of soil alkalinization of sodification, and water Electrical Conductivity (CE), which is an indicator of risk of soil salinization. Most waters were classified as C3S1, with TDS content usually exceeding 480 mg/L, thus restricting their use for irrigation of many crops.

5 Soils

To understand erosion and sediment transportation processes in the microbasin, the effect of rainy season was monitored in two different areas. One had annual crops, level cultivation, dead cover and organic manuring; and the other had brushwood vegetation and native pasture used for livestock.

5.1 Operating monitoring aspects

To understand sediment transportation and accumulation in the microbasin, interventions including the construction of surrounding stone barriers and successive dams were made in areas of annual crops and areas of natural vegetation and native pasture.

5.1.1 Areas of annual crops and natural vegetation and native pasture

<u>Surrounding barriers:</u>
Made of stone and constructed along the "Contour Line", they have the objective of retaining the soil removed by erosion processes. During the monitoring of this area, 28 collectors were installed to retain water and soil, according to a model developed by Professor Anor Fiorini de Carvalho from the Soil Department of Viçosa Federal University (Photo 12).

Photo 12: Water and soil collector

After the rainy event, accumulated water was stored in a homogenized plastic bag and poured into a beaker for volume measurement (Photo 13).

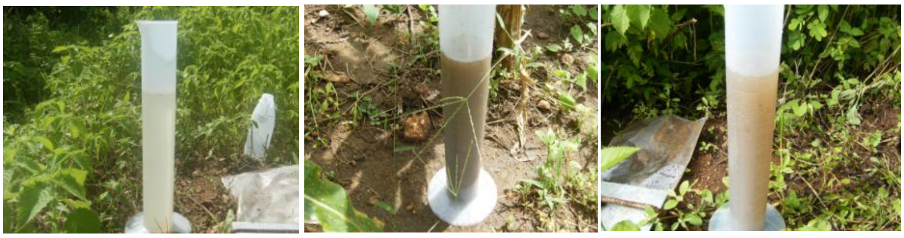

Photo 13: Turbidity difference noted in beakers at volume measurement

<u>Successive Dams</u>:
For monitoring purposes, 150-cm long graduated rulers were affixed upstream and adjacent to successive dams. After the rainy season, final sediment level height was measured on each ruler and then the sediment area was calculated, as shown in Figure 7.

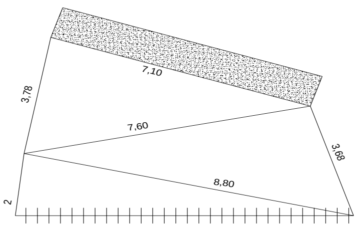

Figure 7: Schematic drawing of sediment area calculation

Several 1-m long, 0.5-m wide trenches were opened, the depth of which varied according to the height of sediments transported and accumulated since the dam construction (Photo 14).

Photo 14: Trench opening and sampling

In general, after rainy season there was sediment accumulation in successive dams monitored in Bananeiras and Guerredo streams, which minimized the impacts or erosion processes and promoted soil and vegetation recomposition in worked areas.

5.1.2 Evaluation of water retained in collectors installed in successive dams

In water samples, main cations and anions electrical conductivity (EC), sodium absorption ratio (RAS), pH, dissolved solids, turbidity and suspended solids were analyzed. Waters were classified on the basis of such parameters, e.g., C1S1.

5.1.3 Evaluation of soil retained in collectors installed in successive dams

Soil samples related to sediments retained in collector were sent to the Soil laboratory of UFC/Funceme for physical and chemical characterization.

Soil profiles showed a sandy, loamy sand, loamy, and sandy loam texture domain. Regarding the sorting complex, there is likely a high susceptibility to erosion and low cation exchange (CTC) capacity. However, organic matter contents are high, showing that the organic fraction is partly responsible for CTC in those soils.

6 Vegetation

A floristic and phytosociological survey was made in two 800-m^2 plots, including the collection of flora specimens and vegetation data (phytosociology, vegetative structure, soil cover and biomass). "Plot 1" was located in a successive dam area close to a small stream

(Photo 15), and "Plot 2" was located in a reforestation area on the margins of Cangati River (Photo 16).

Inclusion criterion adopted for phytosociological data collection and tree count was that of soil level diameter, (DNS) > 3 cm, which is traditionally used for phytosociological Brushwood studies, RODAL *et al.* (1992).

Photo 15: Successive dam in Plot 1

Vegetation appearance in this Plot it that of "Steppe-like Wooded Savannah", with small and low-density trees. It is surrounded by crops and seems to be associated with past deforestation. Accumulated sediments are noted on the left.

Photo 16: Reforestation on Cangati River margins

This Plot is located in the district of Iguaçu. That is a plain area fully included in a floodplain and subject to floods in heavy precipitation times, Reforestation started around 2000. It contains relatively dense and regularly spaced trees with an average height of 5-6 meters, similar to a "Steppe-Like Wooded Savannah" (Arboreous Brushwood), even though the trees are ordinate and have a fully different floristic constitution.

In both Plots 358 trees were recorded, with predominance of brushwood types (angico, pau-ferro, jurema, marmeleiro, sabiá, pinhão, mofumbo, catingueira, juazeiro, trapiá, pau-branco, and mandacaru, among others, even though other exotic species (such as hydrangea) and even invasive species (such as leucena and 'viuvinha alegre') have been identified, which are indicative of human presence and environmental degradation.

7 Conclusions and recommendations

Biophysical monitoring of Cangati River microbasin in Ceará effectively contributed to improve the geoenvironmental conditions in the surveyed region. Resulting data were considered as inputs for: studies of estimated water potentialities; quantification of surface runoff; understanding of transportation dynamics; sediment accumulation in successive dams; understanding of water quality; ciliary forest recovery; reduction of sanding-up process in reservoirs; increase of soil moisture; increase of productivity related to dry land agriculture; and population’s awareness of sustainable use and preservation of natural resources.

It is therefore evident the need of continuity of actions, and it is recommended that this project is replicated in other areas of endangered geoenvironment.

On surface water quality:

- In most monitored reservoirs, hydrochemical revealed mixed bicarbonated waters;

- TDS values in waters of most reservoirs included in the study showed no restrictions to use (class-2 fresh waters, according to CONAMA Resolution no. 357/2005). After conventional treatment, such waters may be used for human consumption;

- With respect to water quality for irrigation, C2S1 type predominate.

On underground dams:

- In the short term, underground dams proved efficient, as groundwater levels in the area of influence of dams (upstream) recorded the greater oscillations among all monitored points during the rainy period (recharge), by reaching almost 100% of sedimentary package thickness.

- In the long term, the groundwater behavior (levels) were similar both upstream and downstream to underground dams, showing no significant interference of works with natural water runoff;

On groundwater quality:

- Sampled waters failed to comply with human consumption standards established by CONAMA Resolution no. 396/98 (Absence of Thermotolerant Coliforms).

- In most wells, mixed bicarbonated and chlorinated waters predominate;

- Most of groundwater were classified as brackish, with TDS values ranging between 500 and 1,500 mg/L. Only groundwater directly associated with underground dams improved their conditions in relation to that item (TDS content < 500 mg/l): fresh waters) in rainy period (recharge).

- With regard to quality of irrigation water, C3S1 water predominate, which present some risk of soil salinization (high salinity), but no danger of soil alkalinization.

On soil:

- Sediment accumulation in successive dams constructed in Bananeiras and Guerredo streams after the rainy season mitigated the impacts or erosion processes and promoted soil and vegetation recomposition in worked areas;

- With respect to quality of water retained in collectors installed in successive dams, this study has concluded that they do not represent a direct risk of soil salinity problems. This risk is indirect and unlikely to occur; their eventual occurrence would be the result of incorrect irrigation management;

- Sediment accumulation, in addition to mitigating the adverse erosion process effects, improved the physical-chemical soil characteristics and resulted in better low-EC water availability, thus enabling the cultivation of several types of crops.

On Vegetation:

- Based on species identified on sediments during the study, it can be concluded that an environmental recovery process is underway in the microbasin region. However, the delayed start of vegetation monitoring; the unavailability of phenological and vegetative cover data (before PRODHAM action implementation); and the lack of a control group for each plot analyzed have not allowed conclusions to be made on possible effects of such actions on any phenologic or demographic aspects of communities settled in such plots.

- According to data related to vegetation diversity, it is concluded that human intervention in Plot 2 in artificially recomposing the vegetation by reforestation, resulted in a lower equability where the proportion between individuals of different species was not equalitarian, with the predominance of 1 or more species, specifically *Leucaena leucocephala*. It should be pointed out that more equalitarian communities in plot 1 (successive dams) have formed under natural environmental recovery conditions, where species established without any direct human intervention. It is suggested that a control plan is formulated for exotic and invasive species referred to above;

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