SILTING IN THE DENSE RESERVOIR NETWORK OF THE PEREIRA DE MIRANDA CATCHMENT

DANIELY LIRA[1], CRISTIAN TOLEDO[2], GEORGE MAMEDE[3]

ABSTRACT - This study aims to analyze the impacts of the reservoir network within Pereira de Miranda - CE catchment (also called Pentecoste) over sediment transport and storage capacity of the system. The survey of the "damming" was carried out using satellite images. We identified 502 erosion units, derived from overlaying maps of the Universal Soil Loss Equation parameters, which allowed the estimation of localized erosion in the basin and identification of areas potentially generating sediment. In order to estimate silting in Pentecoste reservoir, different system structure scenarios were considered. An average erosion rate of 59 t $ha^{-1}year^{-1}$ was estimated. According to the model, the silting of Pentecoste reservoir may vary from 1.1 to 2.6% per decade, depending on the scenario considered. It is also observed that the reservoirs upstream can retain up to 58% of the sediment that would reach the Pentecoste reservoir. Very small reservoirs with a capacity of up to 100,000 m³, although representing only 1.83% of the system water availability, are able to retain almost 8% of total sediment produced.

KEYWORDS: Sediment generation, sediment retention in reservoirs, semiarid.

ASSOREAMENTO NA DENSA REDE DE RESERVATÓRIOS DA BACIA HIDROGRÁFICA DO AÇUDE PEREIRA DE MIRANDA

RESUMO - O presente estudo tem como objetivo analisar os impactos da rede de reservatórios da bacia hidrográfica do açude Pereira de Miranda - CE (também chamado Pentecoste), no transporte de sedimento e na capacidade de armazenamento do sistema. O levantamento da “açudagem” foi realizado utilizando imagens de satélite. Foram identificadas, no total, 502 unidades de erosão derivadas da sobreposição de mapas dos parâmetros da Equação Universal de Perdas do Solo, o que permitiu a estimativa da erosão localizada na bacia e a identificação de áreas potencialmente geradoras de sedimento. Para estimativa do assoreamento no reservatório Pentecoste, diferentes cenários de estrutura do sistema foram considerados. Foi estimada uma taxa de erosão média, na bacia, de 59 $tha^{-1}ano^{-1}$. De acordo com o modelo, o assoreamento do reservatório Pentecoste pode variar de 1,1 a 2,6% por década, dependendo do cenário considerado. Observa-se ainda que os reservatórios de montante podem reter até 58% do sedimento que chegaria ao açude Pentecoste. Os reservatórios muito pequenos, com capacidade de até 100.000 m³, embora representem apenas 1,83% da disponibilidade hídrica do sistema, são capazes de reter quase 8% do total de sedimento produzido.

PALAVRAS-CHAVE: Geração de sedimentos, retenção de sedimentos em reservatórios, semiárido.

INTRODUCTION

Conflicts between water availability and supply in Northeast region of Brazil, particularly in the semiarid region, have been a recurring problem faced by the government, especially during the dry season. It is a fact that great efforts have been employed with the goal of deploying infrastructures able to provide sufficient water to ensure human and animal supply and make

[1] Engº Agrícola, Mestre, Departamento de Engenharia Agrícola, UFC/Fortaleza – CE, (94) 8167-1729,daniely_lira@hotmail.com
[2] Engº Agrônomo, Doutor, Departamento de Engenharia Agrícola, UFC/Fortaleza – CE, cristianepifanio@yahoo.com.br
[3] Engº Civil, Prof. Doutor, Instituto de Eng. e Desenvolvimento Sustentável, UNILAB/Redenção – CE, mamede@unilab.edu.br
Recebido pelo Conselho Editorial em: 18-10-2012
Aprovado pelo Conselho Editorial em: 16-2-2014

irrigation viable. However, these efforts are not yet, in general, sufficient to solve the problems arising from the water shortage, which causes the populations remain vulnerable to droughts, especially when it comes to the widespread use of water in rural areas (CIRILO et al., 2010).

The conflict over water is already a reality in the Brazilian semiarid region, which covers an area of about one million km^2, with a population of around twenty million inhabitants (GUIMARÃES et al, 2010; SANTOS et al, 2011). The water supply of the region depends largely on surface water accumulated in reservoirs. In Ceará State, for example, 93% of the water supplied to users comes from surface reservoirs (ARAÚJO, 2003; ARAÚJO & PIEDRA, 2009).

The construction of reservoirs for water storage becomes increasingly necessary to meet the growing demand of the population. Aiming to meet the water supply, it is very common that the basins harbor high-density reservoir networks (PISANIELLO, 2011; BOARDMAN & Foster, 2011; MALVEIRA et al, 2012).

These reservoirs enable water storage during the rainy season, to provide the resource during the dry season. Most of these reservoirs were built without an integrated planning, and this led to a chaotic system, extremely difficult to control (MAMEDE et al., 2012).

MAMEDE et al., (2009), performing simulations for water and sediment retention by reservoirs upstream of Benguê basin in Ceará State, with high reservoir density. The authors found that in extremely wet years (in this case, the year of 2004) water retention by reservoirs upstream represented only a percentage of 11%, while for years of normal rainfall, water retention in these reservoirs showed values around 40% of the water volume that would come to the main dam. This water retention, on the other hand, allows a better spatial distribution of water resources, favoring its use by surrounding communities.

ARAÚJO et al. (2010) evaluated the impact of a dense reservoir net on water availability in a basin (Upper Jaguaribe Basin) located in northeast semiarid, and found that the dense reservoir networks is a reality in that region, with positive and negative impacts on water availability.

The main negative impacts of this dense network are high evaporation from the surface reservoirs (which leads to reduced water availability) and increasing complexity of management system. On the other hand, this network allows a better distribution of water resources, benefiting the diffuse population, besides energy rationality with offset upstream from the water supply gravity center, and sediment retention, which results in a lower sedimentation rate of strategic dams (ARAÚJO et al., 2006;).

This study will analyze the impacts of the dense reservoir network from Pereira de Miranda catchment (also known as Pentecoste) on sediment transport in the basin, with retention of the sediment part that would deliver to the reservoir and consequent alteration in the water storage capacity of the system.

MATERIALS AND METHODS

Studied Area - The Pereira de Miranda catchment is one of the Caninde River sub-basins, located in the northern center of Ceará State, belonging to the Curu river basin with an area of approximately 3,230 km^2 (Figure 1). The Pereira de Miranda dam was built from 1950 to1957 and has a storage capacity of 395 hm³.

The Pentecoste catchment has an average annual rainfall of 853.55 mm and a potential annual evaporation observed in a 1463.7-mm class "A" pan. As regional rainfall regime shows high intra-annual and inter-annual variability with rainfall concentrated in few months, usually between February to May, there is a large number of surface reservoirs for water storage during the wet season and availability of this resource during droughts. Still, in case of emptying of the reservoirs, local water demand is provided by emergency projects of pipelines to collect from larger water reservoirs or even with the use of water trucks.

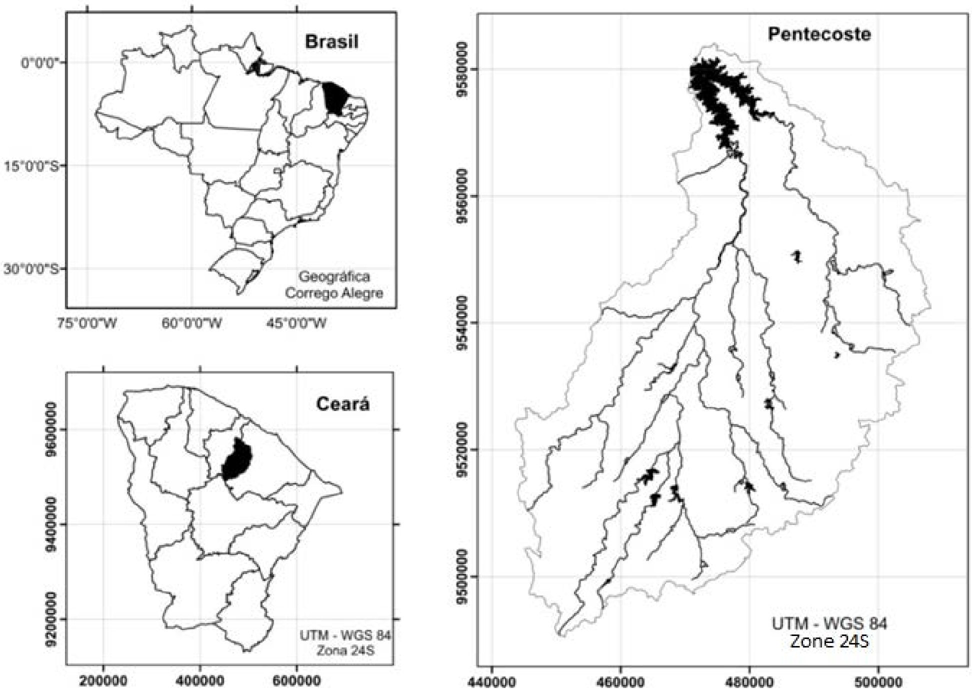

FIGURE 1. Hydrography and location of Pentecoste weir basin.

Identification of reservoirs – In order to quantify the number of reservoirs in the basin satellite images from 1986 and 2004 were obtained (Orbit: 217; Point: 63). The images were obtained at the website of the National Institute for Space Research (INPE), and the satellite used was LANDSAT 5, TM (*Thematic Maper*), with spatial resolution of 30 m.

The images were georeferenced and then classified using the *Bhattachary* technique, which is a classifier supervised by regions. After classification of the images, a database was generated containing the area for each of the 733 reservoirs identified, resulting from the comparative analysis of these images.

The estimated volume stored in the reservoirs began with a survey of the area and depth of ten reservoirs in the field; thus, obtaining the parameters to calculate the level-area-volume of these reservoirs. We adopted the outline method, which is a survey of the reservoirs outlines at different periods with their associated depths.

The reservoir area (Ai) on the technical visit was estimated from survey points along its outline, using an instrument of global positioning system (GPS - Garmin), with average accuracy of 3 m. The maximum reservoir area (A_{max}), in turn, was obtained from the processing and comparison of images of wet periods from the years 1985 and 2004, considered atypical with relatively higher annual precipitation. Therefore, it was assumed that the outlines surveyed on the images corresponded to the maximum area of the reservoirs.

The reservoir depth (h_i) was measured using a digital depth gauge (*Speedtech*), and the gap between the water surface and the spillway level (Δh) with the aid of an optical level. Adding the two height measurements ($h_i + \Delta h$) we obtained the maximum depth of the reservoir studied (h_{max}).

Having the depth values and corresponding areas, the reservoirs volumes were estimated from the use of truncated cone formula (Equation 1). The procedure consists in calculating the cone volume (V_i) represented by h_i height and A_i area. Then the maximum reservoir volume (V_{max}) is calculated, as the sum of the volume V_i and the truncated cone (ΔV) represented by A_i and A_{max} areas and the difference between the h_i and h_{max} heights.

$$\Delta V = \frac{1}{3}\left(h_{max} - h_i\right)\left(A_i + A_{max} + \left(A_i \cdot A_{max}\right)^{\frac{1}{2}}\right) \quad (1)$$

$$V_{max} = V_i + \Delta V \quad (2)$$

To compare the volume obtained by the truncated cone equation, we calculated a new stored volume using Equation 3, proposed by Molle (1989) which was developed based on data from 416 reservoirs located in the semiarid region of northeastern Brazil, and relates the reservoir area in m² (A) and volume in m^3 (V):

$$V = d \cdot \left(\frac{A}{(c \cdot d)}\right)^{\frac{c}{(c-1)}} \quad (3)$$

Wherein: c and d are empirical constants described by the reservoir geometry with mean values of 2.7 and 1,500, respectively (MOLLE, 1989).

In order to verify the Molle equation efficiency, the values obtained were compared with those resulting from the truncated cone equation and analyzed by the Nash - Sutcliffe coefficient.

To estimate the maximum volume of the other reservoirs surveyed in the images, which have no geometrical information, the Molle equation was used again. With these data, it was possible to estimate the maximum water storage capacity of Pentecoste catchment.

Erosion - The Universal Soil Loss Equation (Equation 4) was used to estimate the erosion in the basin, which was developed in a temperate region in the United States, but it is widely applied in Brazil, as follows:

$$M_L = R.K.LS.C.P \quad (4)$$

Wherein: M_L is the average annual soil loss in ton ha^{-1}; R is the rainfall erosivity ($MJ.ha^{-1}$ mm h^{-1}); K is the soil erodibility ($MJ.ha^{-1}.mm.h^{-1}$); LS is the topographic factor (declivity and slope length) (dimensionless); C and P express land use and management and adoption of conservationist practices (dimensionless). The method for calculating each of the parameters is detailed in LIRA (2012).

The localized erosion is estimated by overlapping and multiplying the maps obtained for each parameter from USLE. The average annual R factor was obtained for each of the 33 rainfall gauging stations in the basin and spaced in the basin from isohyetal generated by interpolation for the period 1957-2010. The criterion for selection of these rainfall stations was the existence of historical series with data recorded for more than ten years. To fill potential gaps in monthly rainfall data correlations were made using the method of inverse distance. The K factor, in turn, was determined by sampling for 37 points distributed in throughout the basin, used to determine the erodibility map from interpolation tools. The LS factor was estimated for different slope classes, defined based on the SRTM (Shuttle Radar Topography Mission) data, with a spatial resolution of 92 m. The C factor values were the same adopted in CREUTZFELDT (2006) for the following classes of use identified in the basin, namely: water (C = 0), preserved dense dry forest - caatinga (C = 0.005), open dry forest - caating (C = 0 ,06), degraded dry forest - caatinga (C = 0.3), and the urban center (C = 0.001). The use class definition was based on NDVI vegetation index (Normalized Difference Vegetation Index), which allows identification of reflectance levels for vegetation in various conservation states, and on the information gathered in the field to support the supervised classification process using geoprocessing tools. The satellite image from Landsat 5 TM from June 19th 1991 (Orbit: 217; Point: 63) was used to generate the NDVI.

The choice of the image is due to oldness and absence low cloud cover for the region on the data basis searched. This suggests, by streamlining, that the used soil map derived from the processing of this image using NDVI can better represent the average characteristics of the basin in the simulation period (1957-2010), than if other newer images were used. Finally, for the P factor, a value of one was admitted, characterizing the absence of conservationist practices.

Production of sediment and retention in the reservoirs - The estimated generation of sediment in the basin was performed using the Universal Soil Loss Equation (USLE), associated to the sediment delivery ratio (SDR), as follows:

$$\mathbf{P_S = M_L . SDR} \qquad (5)$$

Wherein: P_S = generation of sediment (t); ML = Mass eroded locally in the basin per area unit (t ha^{-1}); SDR = Percentage fraction of eroded sediment that can reach the drainage net. The SDR was calculated for the entire basin from the MANER equation (ARAÚJO, 2003), which mainly considers the effect of declivity in the terrain in the diffuse transport and is given by:

$$Log(SDR\%) = 2{,}943 - 0{,}824 . Log\left(\frac{L_m}{F_r}\right) \qquad (6)$$

Wherein: L_m is the maximum basin length, straight, measured parallel to the main river in meters; F_r is the difference between the average level of the watershed contour and the basin outlet level, in meters.

The calculation of retention efficiency of sediments flowing into the reservoirs (E_r) was done using the method proposed by BRUNE (1953), developed empirically by analyzing the behavior of American reservoirs. According to BRUNE (1953), retention efficiency is a direct function of reservoir lifetime average, calculated by the ratio between the reservoir capacity (V) and the annual average runoff (Q_a).

To estimate the silted volume in the reservoirs the apparent specific mass of 1.3 g cm^{-3} was used, which was found by ARAÚJO (2003) as an average for the Brazilian semi-arid basins.

Sediment propagation - The sediment propagation in the basin was accomplished through simplified modeling developed by the Group of Hydrosedimentological Studies of the Semiarid (Hidrosed).

The spatial structure of the one-dimensional model is composed of sub-basins, with subdivisions into spatial erosion units derived from the map overlaying, as explained earlier.

The estimated erosion, siltation and sediment production is performed according to the natural propagation order of the flow and hence the sediment transport in the basin, i.e., from upstream to downstream, within the monthly time step (Figure 2). In this way, the erosion of each spatial unit is computed using the USLE, derived from the multiplication of parameter maps; sediment production is determined, multiplying erosion by sediment delivery rate SDR, estimated for the entire basin. The contribution from the effluent sediment discharge from sub-basins located upstream contribute to sediment production. The sediment retention is estimated using the coefficient of Brune and hence the effluent sediment discharge that flows directly into the next sub-basin downstream, at the same time step; and silting is calculated in volume units from the dry bulk density.

To estimate silting in reservoirs located in the Pentecoste catchment, three different scenarios were considered, as follows:

- Scenario 1, which corresponds to the simulation of silting in Pentecoste reservoir without considering other existing reservoirs in the basin.

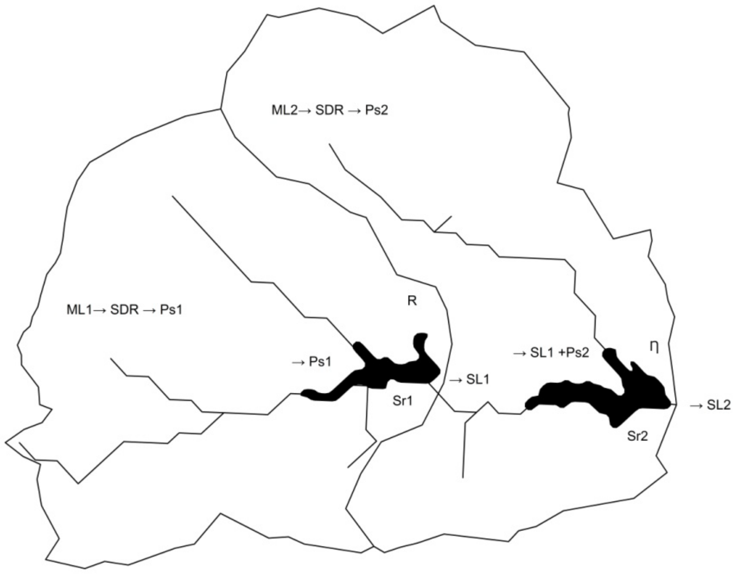

FIGURE 2. Statement of the sediment balance using modeling developed by Hidrosed Group.

- Scenario 2, in which we consider the existing major reservoirs in the basin for silting simulation in Pentecoste reservoir. In this scenario, the area was divided into sub-basins drawn based on the location of the eight strategic reservoirs (strategic means the ones monitored by COGERH, generally used for large urban centers supply and irrigation projects), complemented by other sub-basins defined to obtain more homogeneous areas. Sediment spread through the simplified model presented above, considers the contributions of direct sediment from the uncontrolled area and those from reservoirs located upstream;
- Scenario 3, where siltation in Pentecost reservoir is estimated considering all existing reservoirs in the basin, identified based on satellite images from the years 1985 and 2004. Similar to scenario 2, sediment spread in the basin runs through all connected reservoirs, at the same time step, considering direct sediment contributions generated and those from the upstream basins.

RESULTS AND DISCUSSION

Comparison of the amounts obtained through the truncated cone equation and the Molle equation, as shown in Figure 3, had a determination coefficient R^2 of 0.84 with Nash-Sutcliffe coefficient of 0.81.

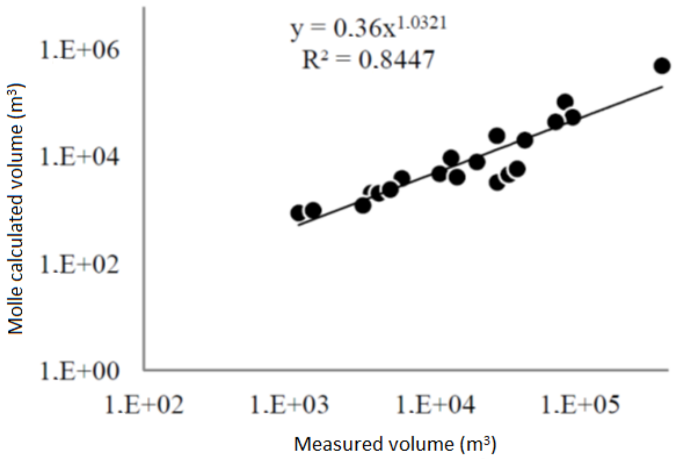

FIGURE 3. Comparative graph for volumes obtained by truncated cone and Molle equation.

After noting that Molle equation (1989) works very well to the studied region, we proceeded to calculate the volume stored in the basin for the different studied seasons. Additionally, the division of the reservoirs collected in five size classes was made taking into account the storage capacity according to Brazilian Decree N^{o}. 23068, from February 11, 1994 (published in the Official State Gazette – DOE from February 18, 1994), as shown in Table 1.

We observed a total volume of 621.3 m³ stored in the basin. Although the class 1 reservoirs have a frequency of 72% in the basin, they are responsible for the storage of only 2.2% of the total accumulated thereon, while the class 5 reservoir accounts for nearly 64%.

Table 2 compares the average parameter values used to estimate erosion, sediment production and siltation in the Pentecoste cacthment, estimated in this study with values found by Araújo (2003) for seven other basins of Brazilian Semiarid region. As observed, the parameters estimated in this study are included in the values reported by Araújo (2003), except for soil erodibility, showing that in this basin soils are more susceptible to erosion.

TABLE 1. Reservoir classes of Pentecoste weir basin, based on water storage capacity.

Class	Interval (hm³)	Number of reservoir	Volume (hm³)	Frequency (%)
1	< 0,1	530	13.86	72.31
2	0,1 – 1	163	50.27	22.24
3	1 – 10	37	120.36	5.05
4	10 – 100	2	41.18	0.27
5	> 100	1	395.63	0.14
	Summary	733	621.33	100

TABLE 2. Average value comparative of Pentecoste weir basin with average values found by Araújo (2003) for seven other basins from Brazilian semiarid region.

Parameter	Pentecoste	Other basins (Araújo, 2003)
R factor (MJ ha^{-1} mm h^{-1})	7093	7734 (6106–9923)
K factor (ton h MJ^{-1} mm^{-1})	0.045	0.026 (0.013–0.037)
LS factor (-)	0.750	1.6 (0.2–2.7)
C factor (-)	0.057	0.093 (0.014–0.192)
SDR (-)	0.073	0.197 (0.072–0.353)
Brune coefficient (-)	0.980	0.974 (0.95–0.98)

From the matrix resulting from the USLE factors product, we verified the occurrence of 502 different erosion units distributed throughout the basin, with values ranging from 0-18590 ton ha^{-1} year^{-1}. The average erosion rate was 59 ton ha^{-1} year^{-1}, which corresponds to an overall erosion of 18.7 million tons per year for the entire basin. The values of localized erosion were classified according to erosion degree proposed by FAO (1980), as shown in Figure 4. As observed, about 80% of the studied basin showed low to moderate erosion rate, with high rates in mountain foothills at the headwaters of the basin, in areas with steep slopes and unprotected soil.

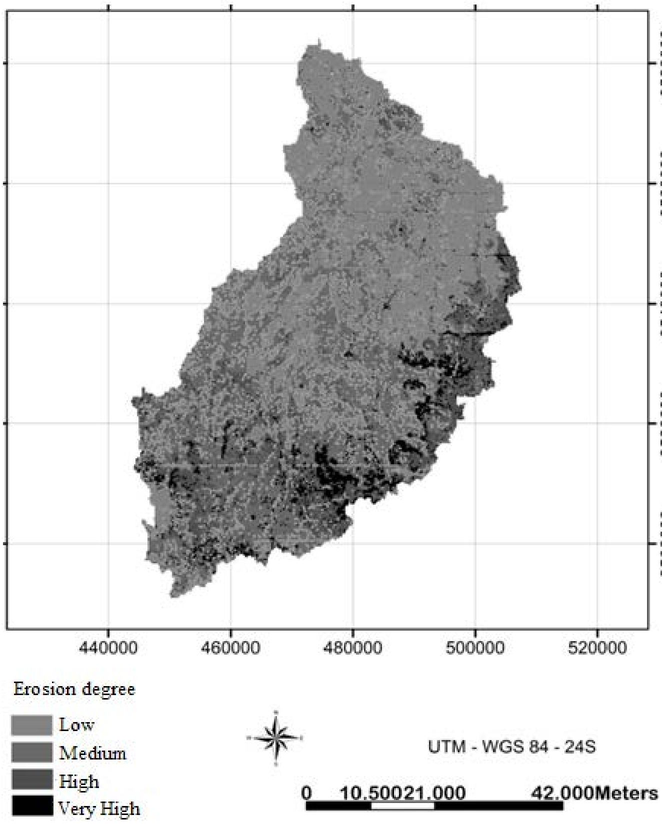

FIGURE 1. Erosion degree classification of the Pentecoste catchment according to Food and Agriculture Organization of United Nations (FAO).

For the estimation of sediment production, a sediment delivery rate SDR corresponding to 7.3% was found, i.e., from the total annual sediment eroded locally (18.7 million ton year^{-1}), only 1.36 million ton year^{-1} reach annually the drainage network and get to the reservoirs.

The sediment retention coefficient proposed by Brune (1953) was estimated for two reservoirs in the basin that had in the data average annual affluent flow, Pentecoste and São Mateus reservoirs, with values of 0.98 and 0.94, respectively. To estimate the retention coefficient of the other reservoirs a regression equation generated from the storage capacity (V) data was used, as well as the Brune retention coefficient (n) for the two weirs, as follows:

$$\mathbf{n = 0.7718\ V^{0}.0123} \quad (7)$$

According to the obtained equation, the retention coefficients of Brune for the other reservoirs in the basin ranged from 0.81 to 0,98. Despite using only two points to estimate the equation, it is assumed that the variability of the values found in the extrapolation can better represent the hydrologic behavior, especially of small reservoirs, which usually spill water more often than if a constant value for the basin reservoirs were adopted.

The sediment propagation in the basin considering the three different scenarios resulted in the following spatial configurations: a single basin subdivided into 502 erosion units (scenario 1); 26 demarcated sub-basins based on the eight strategic reservoirs and other subbasins defined for standardization of spatial unit sizes (scenario 2),as shown in Figure 5; and 733 existing reservoirs in the basin, identified based on satellite images from years 1985 and 2004 (scenario 3).

Table 3 presents the main erosion results, sediment production and siltation at the Pentecoste reservoir, considering the different system configurations (scenarios 1-3), for the 54 simulation years (1957-2010).

Although the same erosion units have been considered, there is a discrepancy in the erosion values for the basin, which can be explained by inaccuracies in the calculation procedures of the variables used in the scales (Table 3). The silting rate in Pentecoste reservoir was higher in the first scenario (2.58%.decade^{-1}) when compared to scenarios 2 (1.70 %.decade^{-1}) and 3 (1.08%.decade^{-1}). This is due to the increase in upstream reservoirs from the strategic reservoir; this causes the silting rate per decade to be lower in scenarios 2 and 3 because of retention in upstream reservoirs.

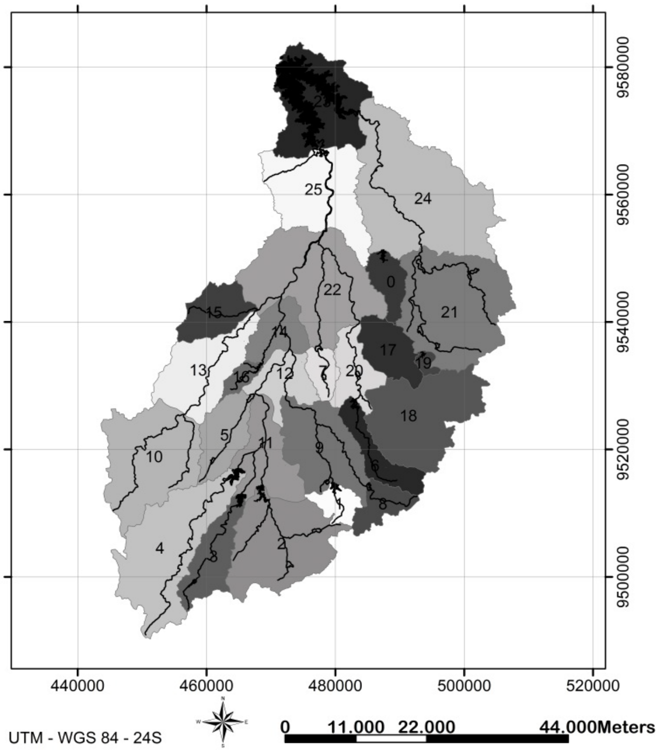

FIGURE 5. Pentecoste Weir basin divided into 26 sub-basins.

TABLE 3. Main results of hydrosedimentological process simulations in Pentecoste Weir basin for the considered scenarios (1 to 3), over 54 years (1957-2010).

Measurement	Scenario 1	Scenario 2	Scenario 3
Erosion (ton year^{-1})	1.01E+09	1.04E+09	9.82E+08
Sediment production (ton year^{-1})	7.38E+07	4.82E+07	3.03E+07
Silting (ton year^{-1})	7.16E+07	4.75E+07	2.99E+07
Silting rate (ton ha^{-1} year^{-1})	4.17	2.77	1.75
Silting (m³ year^{-1})	5.50E+07	3.65E+07	2.30E+07
Silting rate (% decade^{-1})	2.58	1.70	1.08

Silting rate measured by COGERH after bathymetric survey in 2009 was 1.53% in the decade. Araújo (2003) found an average rate of 1.83% per decade for seven other reservoirs in the state. Comparing the silting rate results in the three scenarios with those derived from bathymetric surveys, it can be seen that although scenario 2 (with 26 sub-basins) has come closer to the measured value, the model can be much more sensitive to variations in the USLE parameters, especially in the C factor values, with high variability in magnitude (0.001 to 0.3) than in the system configuration (scenarios 1-3).

The simulation result for the third scenario (silting for the 733 reservoirs in the basin) provides us with a sediment balance by reservoirs class, as detailed in Table 4.

Although small containers (class 1) are inefficient from the hydrological point of view (with 1.83% of the basin storage capacity), they were able to retain 7.72% of the sediment generated. Lima Neto et al. (2011) found the sediment distribution percentages for the Upper Jaguaribe basin of 5% for small reservoirs that correspond to class 1 in this study.

Reservoirs classes 1 to 4 retained 58% of the sediment generated in the basin. In other words, the strategic reservoir receives only 42% of the sediment generated, prolonging its life.

TABLE 4. Main results for 54 year of simulations (1957-2010) of hydrosedimentological processes for different reservoir size classification (scenario 3)

Class	Erosion (ton)	Sediment production (ton)	Affluent solid load (ton)	Silting (ton)	Silting (m³)
1	1.85E+08	1.35E+07	1.42E+07	5.50E+06	4.23E+06
2	1.55E+08	1.13E+07	1.29E+07	8.32E+06	6.40E+06
3	2.05E+08	1.49E+07	1.80E+07	1.60E+07	1.23E+07
4	1.21E+08	8.86E+06	1.21E+07	1.15E+07	8.82E+06
5	3.16E+08	2.30E+07	3.04E+07	2.99E+07	2.30E+07
Total	9.82E+08	7.16E+07	8.76E+07	7.12E+07	5.47E+07

The storage capacity variability of the Pentecoste catchment was estimated by simplified model considering a scenario with 733 reservoirs, for the 54 years of simulation (1957-2010). Storage capacity decay of the system is shown in Figure 6, taking into account all reservoirs in the basin and the Pentecoste reservoir alone, during the simulation period.

As seen in Figure 6, the reduction in water storage capacity occurs more markedly in the system as a whole than that observed in the Pentecoste reservoir, which may be explained by the fact that upstream reservoirs retain most of the sediment (about 58%) that would reach the Pentecoste reservoir . These results enhance the importance of small damming, not only by allowing better spatial distribution of water, but also in sediment retention, benefiting the strategic reservoirs located upstream.

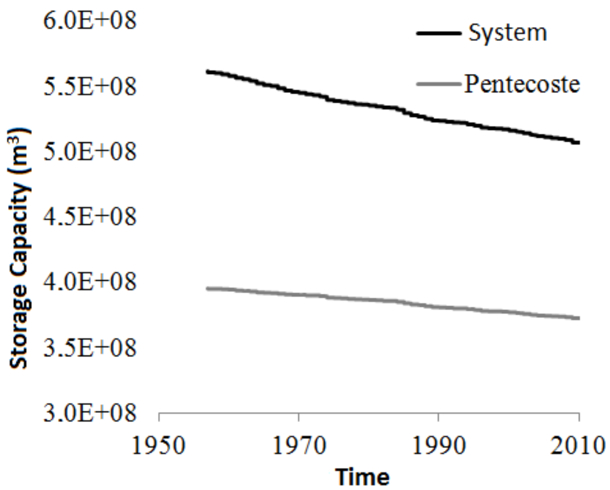

FIGURE 6. Storage capacity decay in Pentecoste weir.

CONCLUSIONS

The comparison between the volume measured and the volume calculated by the Molle method presented an markedly good correlation , justifying the application of the method for the studied area.

The method applied in this study, combining satellite images processing with field survey enabled the identification and characterization of a large number of reservoirs that, up to that point, had no information on their geometrical characteristics and water availability.

The simplified model proposed in this study allowed for a spatially distributed analysis of sediment dynamics along the superficial reservoir network from Pentecoste catchment, as well as the estimated capacity of these hydraulic structures in sediment retaining. In the study, a low to moderate erosion rate was observed in most of the basin and higher values in the hills range where steep slopes and unprotected soil are observed.

The analysis considering different scenarios of system structure, taking into consideration the number of reservoirs upstream of Pereira de Miranda, allowed for a better understanding of the impact of damming over sediment supply for this reservoir. The results showed that upstream reservoirs could retain part of the generated sediment, reaching 58% of the total; in case of the most realistic scenario, that considers all existing reservoirs in the basin (scenario 3). In the simulation considering only the strategic reservoirs (scenario 2), sediment retention is reduced to 20%.

REFERENCES

ARAÚJO, J. C.; LIMA NETO, I. E. ; WIEGAND, M. C. ; MALVEIRA, V. T. C. Impact of a dense reservoir network on water availability in the semiarid north-eastern Brazil. Wallingford : IAHS, 2010. v. 1.

ARAÚJO, J. C.; PIEDRA, J. I. G. Comparative hydrology: analysis of a semiarid and a humid tropical watershed. *Hydrological Processes*, Lancaster, UK, v. 23, p. 1169-1178, 2009.

ARAÚJO, J.C. de; GÜNTNER, A.; BRONSTERT, A. Loss of reservoir volume by sediment deposition and its impact on water availability in semiarid Brazil. *Hydrological Sciences Journal*, Oxford, v. 51, n. 1, p. 157-170, 2006.

ARAÚJO, J. C. de. Assoreamento em reservatórios do semi-árido: modelagem e validação. *Revista Brasileira de Recursos Hídricos,* Porto Alegre, v. 8 n.2, p. 39–56, 2003.

BOARDMAN, J.; FOSTER, I. D. L. The potential significance of the breaching of small farm dams in the Sneeuberg region, South Africa. *Journal Soils Sediments*, Berlim, v. 11, p. 1456–1465, 2011.

BRUNE, G. M. Trap Efficiency of Reservoirs. *Transactins American Geophisical Union,* v. 34, n. 3, 1953.

CIRILO, J. A.; MONTENEGRO, S. M. G. L.; CAMPOS, J. N. B. *A questão da água no semiárido brasileiro*. In: BICUDO, C.E. de M; TUNDISI, J.G.; SCHEUENSTUHL, M.C.B.. (Org.). *Águas do Brasil análises estratégicas*. São Paulo: Instituto de Botânica, 2010. v. 1, p. 81-91.

CREUTZFELDT, B. N. A. *Remote sensing based characterisation of land cover and terrain properties for hydrological modelling in the semi-arid Northeast of Brazil.* Dissertação (Mestrado) – Instituto de Geoecologia, Universidade de Postdam, Postdam, 2006.

FAO. *Metodologia provisional para evaluation de la degradacion de los suelos.* FAO/PNUMA, 1980. 86 p.

GUIMARÃES, A. M.; GARCIA, C. S.; LOPES, L. S.; JÚNIOR, A. M. Expansão do setor sucroalcooleiro e conflitos gerados pelo uso da água na bacia hidrográfica do rio Meia Ponte. *Enciclopédia Biosfera*, Goiânia, v. 6, n. 9, 2010.

LIMA NETO, I. E.; WIEGAND, M. C.; DE ARAÚJO, J. C. Sediment redistribution due to a dense reservoir network in a large semi-arid Brazilian basin, *Hydrological Sciences Journal*, Oxford, v. 56, n. 2, p. 319 — 333, 2011.

LIRA, D. L. C. *Assoreamento em densas redes de reservatórios: o caso da bacia hidrográfica da barragem pereira de miranda, CE.* 2012. 86 f. Dissertação (Mestrado em Engenharia Agrícola), Universidade Federal do Ceará, Fortaleza, 2012.

MALVEIRA, V.T.C.; ARAÚJO, J.C.; GÜNTNER, A. Hydrological impact of a high-density reservoir network in the semiarid north-eastern Brazil. *Journal of Hydrologic Engineering*, Reston, v. 17, p. 109-117, 2012.

MAMEDE, G. L. et al. Overspill avalanching in a dense reservoir network. *Proceedings of the National Academy of Sciences of the United States of America*, Washington, v.109, n.19, p.7191-7195, 2012.

MAMEDE, G. L.; ARAUJO, J. C.; MEDEIROS, P. H. A. Modelagem hidrossedimentológica de pequenos reservatórios da bacia hidrográfica do Benguê. In: NOBUYOSHI, C.; ARAÚJO DO VAL, L.A.; RIBEIRO, M, L.,(Org.). *Produção de sedimentos e seus impactos ambientais, sociais e econômicos.* Campo Grande: Editora Oeste, 2009. p. 393-410.

MOLLE, F. *Evapotranspiration and infiltration losses in small reservoirs.* Série Hidrologia, n.25, SUDENE / ORSTOM, Recife: 1989. (Série Hidrologia, 25)

PISANIELLO, J.D. A comparative review of environmental protection policies and laws involving hazardous private dams: 'appropriate' practice models for safe catchments. *William & Mary Envionmental Law & Policy Review*, Washington, v. 35, p. 515-581. 2011.

SANTOS, J. Y. G.; CUNHA, T. B.; VIANNA, P. C. G. Conflito pelo uso da água no sertão paraibano: o estudo de caso do açude São Francisco II, Teixeira (PB). *Cadernos do Logepa*, João Pessoa, v. 6, n. 2, p. 140-160, 2011.