Main geological characteristics and rainwater catchment in natural tanks in the semi-arid northeastern Brazil

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Abstract: ***Low water availability in semiarid of Paraiba State, especially, water supply diffuse communities, requires alternative technologies for increasing the offer. Therefore, estimate the potential volume of rainwater catchment (VPC) in Natural Tanks (TN), located in Sitio Olho D'Água, Pocinhos, PB, and describe the main geological features were the main objectives of this work. We used a series of rainfall, courtesy of the Executive Agency of Water Management in Paraíba, which was analyzed by climatologically statistics of criteria that set the rainfall patterns at different levels of probability. The annual volumes of water intake were determined for six scenarios of rainfall due to the catchment area of the NTs and geological description, based on texture, color, mineralogical composition and weathering processes, by exfoliation, appearance of secondary minerals and the presence of plants. The main results indicated that rainfall patterns are irregular and asymmetrical, TN is inserted on plutonic rocks and there are indications the three types of weathering. The expansion of access to water stored in rocks tanks ensures coexistence in the semiarid, though the accuracy of the VPC need to establish local rainfall patterns.***

Keywords: rainfall, semiarid, dealing with drought, weathering of rocks.

1. Introduction

The northeast of Brazil is the second most populous region of the country, but which has the lowest percentage of water (about 3%). Besides, the underground is formed predominantly by a crystalline base where water reserves occur in fractures and rocks fissures. Thus, the aquifer zones are limited and located typically in narrow strips, winding and interconnected, accompanying fault zones and fractures [1].

The geological characteristics of the northeastern semiarid region are more difficult to overcome than in other semiarid regions, why is the domain of the rocks of the crystalline geological substratum almost impermeable [2].

This condition prevails also in most of the state of the territory of the Paraiba state, Brazil, where hard rock and very old form said crystalline complex. The flow rates of wells are low (around 1 $m^3.h^{-1}$) and the water has high salinity content [3].

Therefore, the main alternative is to stop the runoff of large and small dams. These types of water impoundment have symbolic values, cultural and outstanding features in the country landscape [4]. However, most ponds stores a small volume of water and thus provide back the population supply needs and animal consumption for a very short time, usually no more than half the dry period.

As the surface drainage of the water of the rain represents to main and/or only source of feedback of the water springs of the Brazilian northeast, the volumes of water stored, form movable reservations, why is the water used out of the places where happened the rains [5].

The communities are discovering how to resolve the water problem in land management in Semi-Arid Brazil: it has to be managed in different ways, using all the available kinds of water supply [6]. Besides the use of green water conserving technologies, other experiences are carried out that provide water supply for agriculture such as cisterns for supplemental irrigation of vegetable gardens, rock cisterns for water for livestock, subsurface dams, catchments of rainwater diverted from roads [7].

The use of natural tanks, as alternative source to capture and to store rainwater in the Brazilian semiárido, remounts a century XIX [8]. These rock outcrops are found in semiarid region of northeastern Brazil and, in general, have no definite use and result dimensions of depression and various forms, wide cracks, baroque or existing natural holes in crystalline rocks, filled by sediments.

The sediment fill the depression is usually compartmentalized into two or three layers [9] and results of rock mechanics and chemical breakdown. The rainwater accumulation in these types of rocky outcrops, occurs in the unfilled by sediments. These water reserves have been used for human and animal consumption for centuries.

Natural tanks were also water supply for the animals of the American mega fauna until about ten thousand years ago. The stored water comes exclusively from the rainwater catchments, this reserve that was consumed by them during the dry season, since there was no more water in the rivers or ponds [10].

Natural tanks were responsible for the water supply of the city of Pocinhos in the state of Paraiba, Brazil, in the last century, and currently is the main water reserve of some rural communities of this municipality [11], although there are these types of outcrops in other areas of northeastern Brazil, which have similar purposes.

Given the importance of natural tanks, to allow increasing the supply of water and, consequently, living in rural areas of the semiarid region of the state of Paraiba, Brazil, it was necessary to describe the main geological characteristics of rocky outcrops, located in Olho D'Água farm, in the territory of the Pocinhos city, Paraiba, Brazil and estimate the potential volume of rainwater harvesting, being those determinations the main objectives.

2. Material and methods

2.1 Main characteristic physics of the study area

The work was carried out, using natural tanks (stones), located in the Olho D'água farm, municipality of Pocinhos, state of Paraiba, Brazil, latitude 7º07'S, longitude 36º06 'W and elevation 650 m.

The city's economy is based on small family farms and subsistence. The climate, according to Koppen climate classification, is the hot semi-arid type (BSh), with an average annual temperature above 18 ^{o}C. The rainfall regime is extremely irregular in amount and distribution and the short rainy season lasts about four months, that is, from March to June [11].

The land area of Pocinhos is inserted in geo-environmental unit of the Borborema Plateau, gneiss-magmatic basement, slightly wavy relief, with few highs and a few outcrops of crystalline rocks.

2.2 Methodological procedures

The monthly and annual data rain- the town of Pocinhos, PB, Brazil, for the period from 01.01.1980 to 31.12.2015, were collected in the rainfall station installed in that location and assigned by the Executive Agency for the Management of State waters of Paraíba (AESA), in Campina Grande, PB.

Totals monthly and annual rainfalls were obtained by making the sum of their daily and monthly values. With these values, it was determined the measures of central tendency (mean and median) and dispersion (standard deviation and amplitude). Other statistical analyzes, more detailed methodological procedures are found in articles [12], [13].

As the "model" of rainfall distribution It is irregular, the median was adopted instead of the average, as measure of central tendency. The total annual rainfall was sorted in ascending order and then calculated the empirical probability (Pr, %) by equation 1:

$$\Pr\ (\%) = \frac{n}{N+1} x100 \qquad (1)$$

Where: n = the number for ordering;

N = the total number of ordination

With the values of Pr, were chosen the at levels of 25, 50 and 75% probability over the total rainfall observed: in the dry year and rainier year and the median value of the series, forming thereby six scenarios of rainfalls.

The catchment's areas of the seven stone tanks were demarcated in the water splitter. With a tape was measured length (L, m) and width (L m) of regular, spaced segments, marked every 50 m

With these measurements, we calculated the partial catchment's areas (APC) and total (ATC, m^2) uptake and potential volumes of rainwater harvesting (VPC, m^3) by the respective equations

$$APC\ (m^2) = C(m) \times L(m) \qquad (2)$$

$$ATC\ (m^2) = \sum_{i=1}^{n} APC \qquad (3)$$

$$VPC\ (m^3) = \frac{\text{rainfall}\ (mm) \times ATC\ (m^2) \times Ce}{1000} \qquad (4)$$

Where: Ce = flow coefficient of water

The description and/or geological reconnaissance of the rock outcrops (natural tanks) were hired, adopting the methodological procedures proposed by [14]Popp (1998), highlighting the following physical characteristics: texture; structure; color; mineralogical composition, SiO_2 content and the occurrence of mode. In addition to the weathering process, that is, the actions of the physical, chemical and biological agents on the rock.

Regarding the use of water stored in the tanks were applied questionnaires to all user families with dealing questions on how to use (human or animal consumption) and water treatment, in addition to the daily consumption of each family.

The calculations, statistical analysis and graphics confections were made using Excel software

3. Results and Discussion

Main features of the rainfall regime

The Figure 1 shows the monthly average distribution of the mean, median and standard deviation of rainfall from the town of Pocinhos, northeastern Brazil.

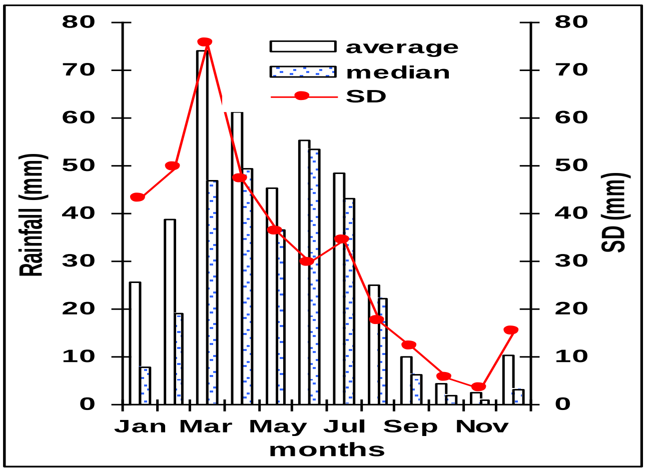

Figure 1: Monthly distribution of the mean, median and standard deviation of rainfall. Pocinhos, Paraiba, Brazil.

It is noted that, rain monthly arithmetic means are always associated with a high variability quantified by their average values of standard deviations (SD). The graphical configuration thus shows that the values of SDs between September and March outweigh the expected average. Even in the months from April to August in which the standard deviations are smaller than average, the values are high which indicates a high irregularity in rainfall patterns.

The variability observed in the rainfall series (Figure 1), compared with the average standard deviation shows that there is a temporal irregularity in the monthly rainfall in that location. This model of rainfall patterns, similar to that found in other drier locations in the state of Paraiba, Brazil, per [15] or in other places in the semi-arid northeast by [16].

When comparing the monthly or annual rainfall series of arithmetic means with their respective medians contact is that the values differ, that is, the averages are always greater than the medians. Thus, the temporal distribution pattern is asymmetric and coefficient is positive. Therefore, it is recommended to use the median instead of the average to be the most likely average value occurs, results that corroborates with the findings by [11], [15], [17] The annual potential volumes of rainwater harvesting in liters per m^2, relative to their average, maximum, minimum and equivalent levels of 25 and 75% probability are shown in Figure 2.

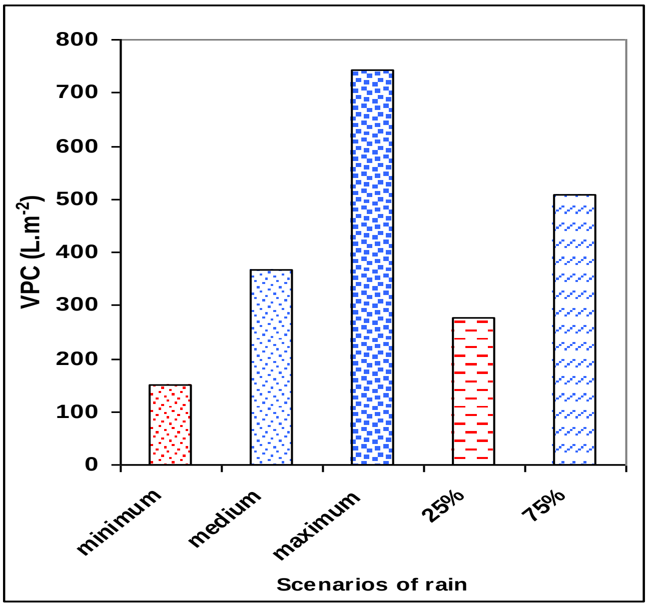

Figure 2: Annual potential volumes of rainwater harvesting, rain for five scenarios. Pocinhos, Paraiba, Brazil.

The chance of rain more than 288 or less than 505 mm, for e example, are 25 and 75% probability, respectively. Assuming the worst rain scenario, which is equivalent to the driest year of the series (1993), it rained 150 mm, the chance to repeat it is very small (<2.9%). This percentage is very similar to what would occur in the rainy year (2013), which precipitated 743.8 mm.

The rocky outcrops include significant areas and presents fractures that reach about seven (07) meters deep. They are aligned in north-south direction as can be seen in Figures 3 and 4.

Figure 3: View of the rocky outcrops on the farm Olho D'Água, Pocinhos, Paraíba, Brazil.
Source: Google Earth (2014).

Figure 4: Image of Stone Tank on the farm Olho D'Água, Pocinhos, Paraíba, Brazil.

The Figures 5 and 6 record some images of these outcrops, highlighting the internal and external positions, natural tanks in the farm Olho D'Água, Pocinhos, Paraiba, Brazil, although there are other structures such territorial areas of this municipality.

Figure 5: View stone tank (with the presence of masonry construction**)** on the farm Olho D'Água, Pocinhos, Paraíba, Brazil.

Figure 6: View stone tank (with the presence of masonry construction and water) on the farm Olho D'Água, Pocinhos, Paraíba, Brazil.

It is observed that these tanks have as main characteristic, the presence of crystalline nuclei, which agree with [17], citing the crystal nuclei arched, are in the east of Rio Grande do Norte, Paraiba, Pernambuco and Alagoas with altitude that can exceed 1000 m.

In addition, they have convex shapes carved in the crystalline represented by intrusive and metamorphic rocks of different ages throughout the Precambrian and form large reservoirs inserted in the rock (Figure 7). The structural control of rocky outcrops is given by the presence of fractures and exfoliations in granite rock, which allow the percolation of water and hence provide conditions for changing the rock. This action has the effect of extending the fractures, as described [8].

Figure 7: View reservoir inserted in the rock (fracture), with water. The farm Olho D'Água, Pocinhos, Paraíba, Brazil.

In the stretch of rocky outcrop (Figure 8), it is perceived that the magmatic body rock is characteristic of a plutonic igneous rock and phaneritic texture, which allows observing the conspicuous single crystals such as mica, quartz, feldspar and iron magnesia. These types of rocks are commonly called coarse grain, for the texture is formed by the slow cooling of magma at depth, causing minerals from clumping.

Figure 8: Plutonic igneous rock (granite), outcrop section. Farm Olho D'Água, Pocinhos, Paraíba, Brazil.

The weathering is a process that changes the physical and chemical rocks and their minerals having principal agent's climate and relief, whose visual recognition of weathering processes can be seen in Figure 9.

It is observed (Figure 9) and the presence of dykes (composed of feldspar), the action of physical weathering resulted in concentric plates or scales on the surface, called exfoliation.

Exfoliation is due to the action of external agents, such as temperature variation, which produces continuous expansion and contraction in the rock. Moreover, the plants which arise in these cavities and/or fractures, the development of root system separate and removes the most different size fragments.

Figure 9: Visualization of physical weathering, with exfoliation and dikes on the rocky outcrop. Farm Olho D'Água, Pocinhos, Paraíba, Brazil.

The chemical weathering as cited [14], occurs when there is a breaking of the chemical structure of the minerals composing the rock or sediment (source material). In this case, the rocks undergo a decomposition process.

The Figure 10 show visible effects of chemical weathering, by the appearance of certain secondary minerals, generated from the change of the original minerals, particularly feldspar and other minerals with significant amounts of Fe and Mg change color, in this case, for a reddish color.

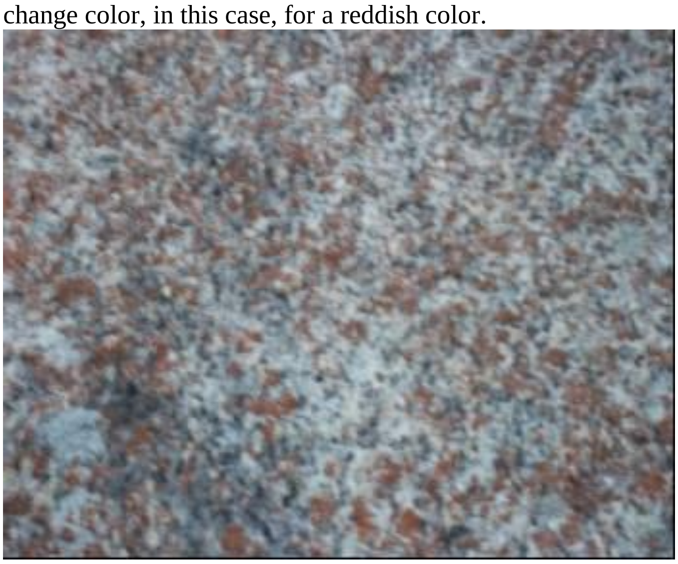

Figure 10: View of chemical weathering, shown in the modification of minerals for a reddish color Farm Olho D'Água, Pocinhos, Paraíba, Brazil.

These results are similar to those found by [14], the name is common modifications of silicates by water. The biological weathering results from the action of bacteria by biotic decomposition of organic materials.

Although there is some discussion of this term, since when an animal trampling the pasture, for example, could be considered erosion or physical action of an animal. It can also be caused by the penetration of tree roots that extend or grind the rock walls or plants in the clefts of the rock as seen in Figure 11.

Figure 11: Biological weathering View (plants in the rock), the rocky outcrop. Farm Olho D'Água, Pocinhos, Paraíba, Brazil.

The emergence of the plants in the rock interstices is why plant remains decomposed facilitate the process of germination and root penetration in the rocks of fractures.

The potential volumes of rain water uptake (VPC) in a natural tank are shown in Figure 12.

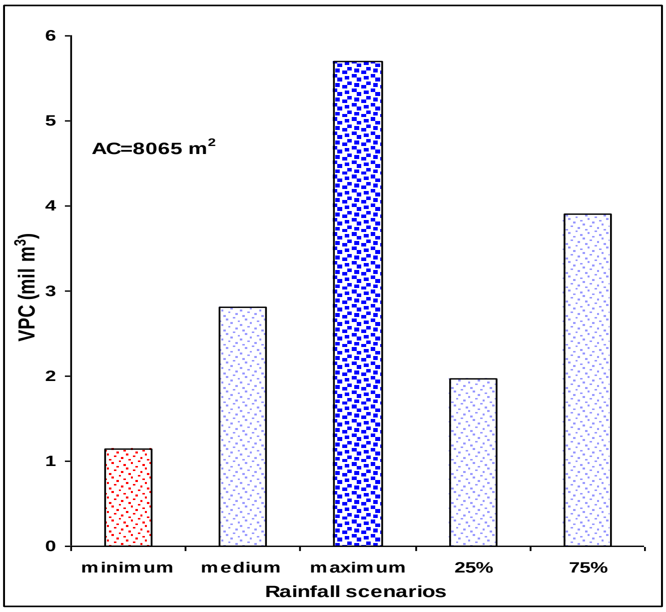

Figure 12: Potential volumes of rainwater harvesting (VPC) on the stone tank, located on farm Olho D'Água, Pocinhos, Paraíba, Brazil.

It is noted, however, that VPC, the median condition of rain, is about 170 times larger than the VPC a residence with 60 m^2 of catchment's area. Adopting a captain per daily consumption of 50 liters for seven months (210 days), the rain interception area of said stone tank would capture, for this condition, about three (3) million liters. This amount is enough to supply a population of 285 people

Simulating to the two extreme conditions, ie the drier year and the 25% level of probability, stone tank has a potential to capture a volume of rain water to supply between 110 and 187 people, respectively.

The high volumes of water stored in natural tanks ensure domestic consumption and animal consumption, and supply activities related to family farming. Therefore, these reservoirs are viable alternatives to living in the semiarid region, proposes by [19]. The Program One Million Cisterns for Drinking Water (P1MC) and the Program One Piece of Land and Two Types of Water (P1+2), are examples of coexistence programs with drought in Semi-Arid Brazil.

However, one can not disregard the item water quality and, therefore, it is recommended that families should improve management techniques, among them the disinfection of water before using it, and deploy a permanent educational work and continuing to ensure the quality of water to be stored.

4. Conclusion

The rocky outcrops are inserted on batholiths plutonic rocks. There are actions of physical, chemical and biological weathering and percolation of water into the rock resulting in the exfoliation process that provides over time, extending the fractures.

The results show the importance of disinfecting the water before consumption. However, to estimate the potential volume of rainwater harvesting, requires the establishment of the main characteristics of the local rainfall regime.

The catchments of rainwater and storage tanks stones ensure greater availability of water for potable and non-potable purposes, and rural living in the semiarid region of the state of Paraiba, Brazil.

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