Chapter 16

Smart rainwater management and its impacts on drought resilience by Rural Semi-Arid communities: a case study of Northeast Brazil

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16.1 INTRODUCTION

There are two different approaches to understanding the semi-arid region of Brazil: the approach of the indigenous people and the approach of the colonizers. On the one hand, the indigenous population called the semi-arid region 'Caatinga' which means grey forest. This is due to the grey colour of the tree vegetation in the dry season. The region was a woodland with a green and a grey period depending of the season of the year. On the other hand, there is the colonizer approach. Portuguese colonizers arrived during the 16th century and began to deforest and burn the Caatinga to plant grass for cattle raising, transforming the region into a 'Drought Polygon'. In the 19th century, during the major drought of 1877 Emperor Peter II proposed to develop the region by the diversion of part of the São Francisco River, deep drilled wells (not appropriated in the mostly crystalline bedrock) and irrigation projects. These two approaches still determine the development projects of the region today.

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Contrary to the colonizer approach, also in the second part of the 19th century, some Brazilian missionaries like Father José Ibiapina in the state of Paraiba, began harvesting rainwater, building in each Mission a 'water house', which was a rock water tank to store rainwater runoff, covered with a tile roof (thus 'water house') to improve the water quality and to diminish evaporation. Father Cicero Romão Batista encouraged in the rural area of the state of Ceará, the construction of rainwater cisterns by every house and of small stone barriers every 100 meters in intermittent streamlets and rivers to catch the rainwater runoff from the Caatinga to be used in the dry season. This chapter focuses on explaining how this understanding resulted in a new vision called 'Living in harmony with the semi-arid climate'. Different rainwater catchment systems technologies are presented as well as their implementation. They ensure safe drinking water for the families, water for the communities, water for agricultural production, water in emergency situations and water for the environment.

16.2 AREA OF REFERENCE

The semi-arid region of Brazil is located in the northeastern part of the country (Figures 16.1 and 16.2). In 2005, the Brazilian Government officially delimited the former drought polygon, calling it Semi-arid Brazil (SAB) (Brazil, 2005). SAB has a yearly rainfall below 800 mm, an aridity index of less than 0.5 and a drought risk of above 60%, calculated between 1970 and 1990. Due to the effects of environmental degradation, drought and climate change, the area of the SAB increased in the

Figures 16.1 Map of Brazil. (*Source*: Author, according to Brazil, 2005 and INSA, 2017).

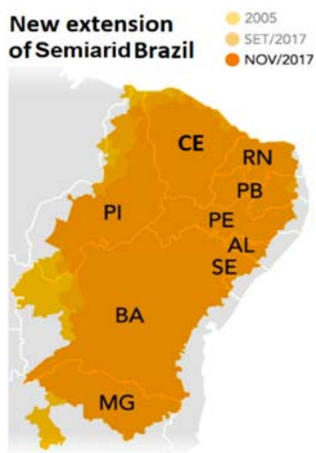

Figure 16.2 Semi-arid region of Brazil. (*Source*: Author, according to Brazil, 2005 and INSA, 2017).

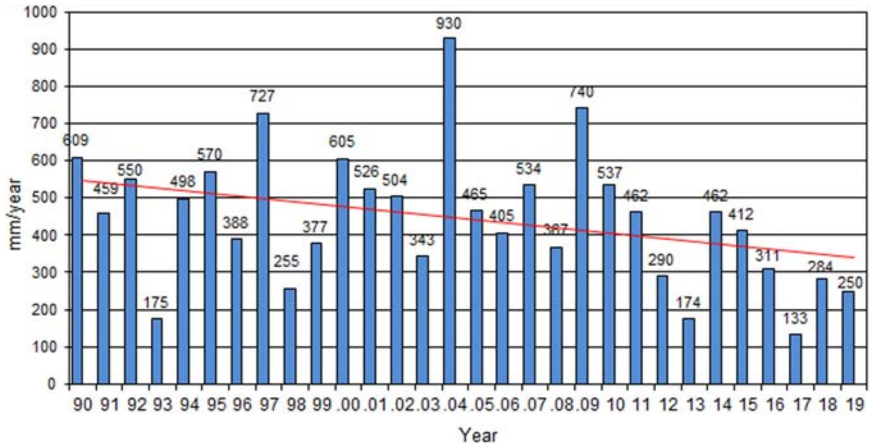

Figure 16.3 Annual rainfall in semi-arid Brazil, Juazeiro (1990–2019) with a trend line of decreasing rainfall. (*Source*: Author, according EMBRAPA, 2019).

last 15 years from 969,600 km^2 to 1,128,000 km^2 with 1262 municipalities, inhabited by 27 million people, 10 million of them live in rural areas (INSA, 2017). Traditionally the people make their living, collecting wood, honey, medical plants, processing wild fruits and raising goats and sheep without cutting down the native vegetation. In this region, the year has two seasons: a four-month rainy season and an eight-month dry season. It is particularly the irregular distributed rainfall in space and time, which characterizes the region. The city of Juazeiro in the center of SAB has an average yearly rainfall of 510 mm. In a drought year there may be only 133 mm rainfall, whereas in another year there could be 930 mm. Rainfall also has been decreasing over the last 30 years (Figure 16.3). Evaporation rate is high, due to continuous high temperatures (open surface evaporation of about 3000 mm a year). Longer droughts are part of this semi-arid climate and occur in a cycle of 25–30 years (Girardi & Girardi, 2001). The last severe drought event occurred between 2012 and 2017. In over 60% of the SAB, there is crystalline impermeable subsoil where it is not advantageous to drill wells. The normally small quantity of saline groundwater is not appropriate for human consumption or irrigation, although sheep and goats may consume it.

16.3 THE ANSWER IS TO LIVE WITH THE SEMI-ARID CLIMATE

When one, two or three years of low rainfall happen, it is not a catastrophe for the semi-arid region's plants and animals. Over a period of thousands of years, nature has been able to adapt itself to the semi-arid climate with its droughts and to build resilience. An event that drew attention was a drought between 1979 and

1983, which provoked immense internal migration, looting of governmental warehouses and which killed nearly up to one million people, especially the elderly and children (IBASE, 1989). While on one side, the corn crops withered in the fields and children starved to death filling the graveyards, the Caatinga region appeared to be beautiful, with their flowers, fruits and animals. Native plants of the Caatinga vegetation accumulate water and nutrient reserves, having tuberous roots and thick trunks to store water or deep roots to fetch it in the fissures of the crystalline subsoil; they avoid unnecessary evaporation; they produce and reproduce less in drought years, but do not die. Contrary to other semi-arid regions of the world, SAB has maintained a large part of its original tree, bush and shrub vegetation, which needs to be preserved and restored. This way the Caatinga keeps its resilience against climate change. The people have a popular saying: 'Preserve the Caatinga because it will resist climate change in the year 2100'. The lesson for the people is that their activities must also follow the concept of preparation for multiple drought years, similar to nature: they need to plan their water supply needs, not only for an eight-month dry season, but also for two years or more of drought.

Since the late 1970s, the Governmental Agricultural Research Center for the Semi-arid Region (EMBRAPA Semi-arid), conducts research on rainwater harvesting systems. In 1990, the Regional Institute of Small-scale Appropriate Agriculture (IRPAA) and other non-governmental organizations started undertaking research and dissemination of rainwater harvesting technologies, as part of the model 'Living in Harmony with the Semi-arid Climate'. During the decade it became necessary to create the institutional basis to implement larger programs, thus the government funded the Brazilian Rainwater Catchment and Management Association (ABCMAC) in July 1999. ABCMAC brings together researchers and users of rainwater technologies and above all, it organizes the biannual Rainwater Catchment and Management Symposium. In 1999, during the 9th International Conference of the Rainwater Catchment Systems Association (IRCSA), held in Petrolina, Pernambuco State, 50 experts from around the world presented experiences of rainwater catchment management. In particular, the successful experience from Gansu province, in the semi-arid region of China, became an example for SAB. In the same year, non-governmental organizations founded the Semiarid Network (ASA), which brought together more than 2000 grassroots organizations, including non-governmental organizations, farmers' unions, cooperatives, associations and church communities. Next, ASA launched the campaign under the slogan 'No family without safe drinking water' and proposed the One Million Cisterns Program (P1MC), to be implemented by civil society in a decentralized way (at the community, municipal, micro-regional, state and semi-arid regional levels). The P1MC was complemented by the Program One Piece of Land and Two Types of Waters (P1 + 2) meaning that every rural family must have: (1) a piece of land large enough to produce food, raise livestock, and ensure a sustainable life; and (2) two types of water storage, one for drinking and another for agricultural production (Gnadlinger, 2007). These two programs were important steps for Living in Harmony with the Semi-arid Climate, which also include other aspects such as agro-ecological food production, goats and sheep husbandry, marketing, contextualized education, political organization and environmental protection, needed to ensure sustainable development of the region. In this way, farmers, animal raisers, community representatives and even policy makers became aware how it is possible to live in harmony with the semi-arid climate and with droughts.

16.4 FIVE STEPS OF (RAIN) WATER MANAGEMENT

Experience has proved that despite the problems of uneven distribution of precipitation, high potential evaporation rates and unfavourable subsoil, it is always possible to catch water when it rains, store it and, therefore, have a safe source of water during the dry season, not only for drinking, but also for other uses (Gnadlinger, 2003, 2011, 2014). Rainwater management is part of the whole water cycle, which includes rainwater, surface water, water in the plants, soil water, groundwater and reuse of wastewater, even evapotranspiration. With infrastructure and good management, it is possible to have sufficient water for different uses in semi-arid communities, as well as during drought periods, especially if the following five steps are considered: (1) Water for families; (2) water for the communities; (3) water for agriculture; (4) water for emergency situations; and (5) water for the environment. These five aspects will be explained below.

16.4.1 Water for families

The most precious water is the one that is for human consumption, thus the supply of drinking water in case of scarcity has priority according to the Brazilian law (Brazil, 1997). For this reason, cistern water should be used first for drinking, cooking and basic hygiene. All families must have access to safe drinking water in quantity and quality. Drinking water should come preferably from cisterns, constructed near the house, large enough to store rainwater caught during the rainy season to be used during the long dry season (Heijnen, 2013). Several cistern designs are well known and used in the SAB. The two most cost-effective designs are: the semi-subsurface cistern made of pre-cast segments (which has user preference) (Figure 16.4) and the self-standing wire-mesh concrete cistern (for sustainability reasons) (Schistek & Gnadlinger, 2011; Thomas, 2001). Diversion of the first rain, removing water from the cistern with a hand pump and filtering the water before consumption guarantee safe drinking water. During the last 19 years around 1.2 million cisterns of 16,000 L for drinking water have been constructed by the organized civil society with funding from the federal government. As of March 1st, 2019, 619,943 cisterns had been constructed for families and 6848

Figure 16.4 One of the cisterns built by the ASA Semi-arid Network. (*Source*: Author).

cisterns of 30,000 L and 52,000 L for schools by ASA (2019). Figure 16.4 shows such a cistern, which especially benefitted women, liberating them from fetching water from long distances, and children, providing them with clean, healthy water.

From 2012 to 2017, the Ministry of National Integration also constructed *PVC (polyethylene plastic)* cisterns, manufactured by a multinational company, but criticized by the civil society because of technical quality problems and lack of community involvement. The P1MC methodology includes local participation in the construction process (hiring local masons, supporting the local economy with the acquisition of building materials, income generation, etc.) definitely advantageous when compared to the PVC cistern project where local participation is minimal, because the tank, the most expensive part, is produced in a factory (ASA, 2011; Heijnen, 2013).

16.4.2 Water for the Community

This water, which is for personal hygiene, washing of dishes and clothes, and for chickens, goats and sheep, may be provided by trench-like rock cisterns and by shallow wells. To guarantee this type of water, a community organization for planning, construction and maintenance is necessary.

Even in drought years, the 4-meter deep trench-like rock reservoirs with a small surface area to prevent evaporation have enough water for the needs of humans, livestock and a small vegetable garden. Figure 16.5 shows an example of this type of reservoir on April 15, 2012, when the picture was taken. The last rain had fallen in February (195 mm) and March (41 mm). The herd of goats had enough water for the following dry months. A similar situation occurred in 2016.

Figure 16.5 A four-meter deep trench-like rock cistern stores water for goats. (*Source*: Author).

To prevent evaporation and to increase the storage volume, one must not increase the width, but the depth and the length of the reservoir. The typical size is 5 meters wide, 4 meters deep and up to 30 meters long (with a storing capacity of 600,000 L). Obviously, it would be more appropriate to increase the reservoir volume by investing in greater depth and less length. However, the geological formation is a limit, because it is common that after four meters of excavation, hard impenetrable bedrock is found (Schistek, 2012).

Furthermore, more than 2000 manual water pumps with a flywheel (called Volanta pumps) were installed by ASA, especially in wells in crystalline subsoil with low output, providing water not only for sheep and goats, but also for other uses, if the water is not saline (Schistek, 2010).

16.4.3 Water for agriculture

Water for agricultural needs is supplied in many ways, including underground cisterns, sub-surface dams, ponds for salvation irrigation, road catchments, contour level plowing, rainwater stored *in situ* for fruit trees or planting crops adapted to dry climate conditions (sorghum, pigeon pea, green gram, sesame, etc.), use of manure and dry organic mulch to retain soil moisture for plants (Gnadlinger *et al.*, 2007).

Underground cisterns are promoted for multipurpose uses. The cisterns are cylindrical with a storage capacity of 52,000 L (Figure 16.6). Rainwater is collected from road catchments or runoff from 200 m^2 catchment areas constructed near the cisterns. These tanks permit supplemental irrigation of fruit trees and small vegetable beds (60 m^2), lined with PVC sheets 30 cm beneath the soil for avoiding water seepage. Until March 1st, 2019, ASA (2019) had constructed 103,528 cisterns of 52,000 L each to irrigate vegetables and fruit trees.

Sub-surface dams, appropriate in crystalline subsoil, store rainwater runoff: a transversal trench is dug (normally from 1.5 to 4 meters deep) perpendicular to an intermittent stream until reaching the impervious subsoil (Silva *et al.*, 2007). A subsurface dam in the SAB is composed of five parts: a catchment area, a storage area (or area for planting), a sub-surface dam, a shallow well and a spillway. The catchment area is the terrain represented by a small watershed where rainwater runoff from a stream or artificial drainage is collected. The storage or planting area is formed by the subsurface water table. When the water is stored in the soil, it is possible to plant all types of vegetables, corn, rice, beans or fruit trees. The dam itself is a perpendicular earthen wall with a PVC sheet placed on the downstream side of the trench, in a vertical position, from the impermeable crystalline rock layer until reaching the soil surface (Figure 16.7), intended to block the flow of surface and subsurface water upstream of the dam. The spillway has the function of eliminating the surplus water of the planting area after a heavy rainfall. A shallow well is dug at the deepest part of the storage area to use its water for livestock or small-scale irrigation.

Figure 16.6 Cistern of 52,000 L with catchment area for irrigation of fruit trees and vegetables, near the house a cistern of 16.000 L with drinking water. (*Source*: Author).

Figure 16.7 Sub-surface dam construction, placing the PVC sheet. (*Source*: Author).

16.4.4 Water for emergency situations

In years of drought, water for emergency situations is provided by deep wells and strategically distributed small and deep dams. This step is an interim solution when the three previous steps of water management are not enough. Over a period of thousands of years, nature has been able to adapt to droughts and build resilience. Supplying water by truck may be inevitable to mitigate the effects of drought, but this method is expensive, water often is of poor quality, and can be misused to make the underprivileged population dependent on politicians. The challenge is to make these programs unnecessary, when the first three steps are achieved. Drilling deep wells and constructing strategically positioned deep reservoirs, which do not dry out in drought years, can be one of the options for the population. However, in the SAB there are thousands of dams, which largely remain in the hands of an elite which do not share the water, leaving the surrounding population without access to that water, contrary to the first Article of the Brazilian Water Law (Brazil, 1997).

In late 2013, during evaluations about living with drought conditions, some examples of solutions were indicated: In the municipality of Palmas de Monte Alto, Bahia state, with an average rainfall of 800 mm, it rained only 300 mm in 2012 and 2013. However, it was enough rain to fill a cistern of 16,000 liters. This water was the best water for drinking, being used only for this purpose. Water provided by truck that came from polluted surface water sources was used only for livestock and vegetable gardens. In Itiúba, Bahia state, with 250 mm of rainfall in two drought years, the cisterns were filled by the water collected from the house roof, because the catchment area was greater than necessary to collect the water in one year of normal rain. It was suggested that every family should have more than one cistern. In this way, they could ensure drinking water with rainwater in drought time: in years of excessive rainfall, they could use water from cisterns also for other uses. In Sobradinho, Bahia state, in the community of Serra Verde, during 2013, from 200 mm of annual rainfall, 140 mm fell on April 22 and 23, 2013, enough to fill the trench-like rock cistern and have water for the livestock, until the next rainy season, which began in December 2013.

16.4.5 Managing water for the environment

Water management for the environment is based on the watershed, protection of springs and riparian vegetation, pollution prevention, wastewater recycling and reuse for irrigation purposes, supporting ecosystems and completing the water cycle of evaporation, condensation and precipitation.

Watershed Management is the integration of technologies within the boundaries of a drainage area for optimum development of land, water and plant resources to meet the basic needs of people and animals in a sustainable manner. The integrated management of small watersheds uses different rainwater harvesting technologies, starting from the highest point of the property/watershed, where the rainwater starts draining subsequently to the lower parts of the watershed.

On the higher parts of the watershed, work is done to promote eco-forestry and reforestation of Caatinga trees (re-caatingamento), plant groundcover plants tolerant to drought, vegetative barriers for soil, with natural pasture. On hillside areas, work should promote planting along contour lines, harvest water ‘in situ’, plant fruit trees and vegetable gardens, build small ponds for infiltration and groundwater recharge, recover gullies from the beginning of the water flow. At the lower parts of the watershed, it is best to use rainwater-harvesting technologies for food production, like subsurface dams, ponds, small gabion dams or successive barriers in streams to store water in the alluvium (See also Qiang & Li, 2009). A variety of watershed management programs in temporary rivers called hydro-environmental projects and natural vegetation recovery programs, called ‘re-caatingamento’, are underway.

These five steps of water management make it possible to live with the semi-arid climate conditions and are the basis of the elaboration of decentralized and participative water plans, to be carried out in communities and municipalities of the SAB. They mean a paradigm shift in the management of water resources as opposed to large technical projects for the formerly so-called ‘Drought Polygon’.

16.5 EVALUATION AND OUTLOOK

The rainwater management programs executed principally by ASA with governmental financing are a success story. ‘We came from 1 million dead people to 1 million cisterns. In the drought of 1979 to 1982, about 1 million people in the Northeast died of starvation, that is, hunger or thirst. In the drought that lasted from 2012 to 2017, there are no records of deaths by starvation, no large migrations, no emergencies and much less looting in the cities of the hinterland' (Malvezzi, 2016). Strategic actions to control environmental degradation were carried out in partnership with communities, governments and popular movements. Thus, hundreds of people participated in simplified water management courses for food production, which aims to teach about how to care for the soil, animals and plants, thus enabling food production with better quality. These measures contributed to food security, poverty alleviation and resilience also in drought years (IRPAA, 2012). During this time, Pernambuco and Bahia state governments promulgated 'Living in Harmony with Semi-arid Climate' laws (Bahia, 2016; Pernambuco, 2013). When in the future the political situation will once again be favorable, the people of SAB will work to achieve a similar federal law.

The One Million Cisterns Program received the Future Policy Award 2017 during the 13th Conference of the Parties of the UN Convention to Combat Desertification in Ordos, China, because it 'is a participative, bottom-up way to provide water for consumption, for producing food and raising livestock in Brazil's drought-prone semi-arid region using simple rainwater collection technology. It empowers millions of the region's poorest people to be in control of their own needs, to generate income and enhance their food security' (World Future Council, 2017). In our understanding, the award may encourage other semi-arid regions of the world to carry out RWH projects, taking into account the different environmental, social, technological, economic and political factors as the FAO (2018) initiative "One million cisterns for the Sahel". Rainwater management programs are part of the sustainable development program 'Living in Harmony with the Semi-arid Climate'. According to the principle of subsidiarity, appropriate technologies supported by public funds, are carried out by families and local communities, and guarantee their participation during the implementation and maintenance. Inclusion of women is a vital ingredient for social betterment along with economic efficiency. A strong political organization of the civil society in Northeast Brazil at the local level and its networking at the state and federal level, also assist family farmers to improve their living conditions.

Now these achievements gained through public policies are at risk because of reduced support of rainwater harvesting programs by the federal government. In addition, the return of technological state-driven policies are associated with preferably large-scale interventions such as mining, energy and irrigation projects, which destroy the Caatinga, exploit natural resources, with little or no benefit to the local population. At the same time and perhaps still more serious, the changes in the climate, such as less rainfall, higher evaporation rate, longer lasting droughts and desertification create new environmental and economic conditions and challenges.

'Resilience is the capacity of a system, be it an individual, a forest, a city or an economy, to deal with change and continue to develop. It is about the capacity to use shocks and disturbances, such as a financial crisis or climate change, to spur renewal and innovative thinking. Resilience thinking embraces learning, diversity and above all, the belief that humans and nature are strongly coupled, to the point that they should be conceived as one social-ecological system' (Moberg & Simonsen, 2014). The people of SAB are aware of this.

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