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# Harvesting Water for Living with Drought: Insights from the Brazilian Human Coexistence with Semi-Aridity Approach towards Achieving the Sustainable Development Goals

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**Abstract:** The Semi-Arid region of Brazil (SAB) has been periodically affected by moderate to extreme droughts, jeopardizing livelihoods and severely impacting the life standards of millions of family farmers. In the early 1990s the Human Coexistence with Semi-Aridity (HCSA) emerged as a development approach. The debate on HCSA is limited to Brazilian literature but as a technological and a bottom-up governance experience, researches on the topic could add some insights to international debate on living with drought. The present paper adopts an historical perspective on HCSA before discussing the main HCSA's rainwater-harvesting methods found in two case studies in the SAB as a local appropriate and advanced technological package for achieving Sustainable Development Goals (SDG). Qualitative analysis of 32 semi-structured interviews with key local stakeholders, 29 unstructured interviews with family farmers, and surveys in 499 family farms are used. The results show that regardless the highly adaptive potential, the technologies are adopted in differ rates among them and in between case studies chosen, influenced by non-technological factors and interacting the broader public policies context. Scaling up the HCSA's technologies in the rural SAB is a development path towards the SDGs.

**Keywords:** semi-arid; drought; sustainable development goals; rainwater harvesting; family farming; living with drought; bottom-up governance; climate adaptation

## 1. Introduction

The Semi-Arid region of Brazil (SAB) is one of the most populated semi-arid areas in the world [1]. The SAB's territory covers roughly 12% of the national area (982,563 km<sup>2</sup>), 1134 municipalities and a population of 22.6 million [2,3]. In the region, about 4 million smallholder farms dependent on rain-fed agriculture are vulnerable to climate variations when it comes to producing food, their water supply and generating income [4]. Historically, the region has been periodically affected by moderate to extreme droughts, jeopardizing livelihoods and severely impacting the life standards, resulting until recently in widespread famine, forced emigration and, still today, asset losses.

The rural population in the SAB has adapted to a context of water scarcity by using traditional rainwater harvesting (RWH) technologies, mainly consisting of superficial reservoirs excavated in the drainage basins of small rivers and streams, capturing and storing surface run-off in open dams

“açudes”) and farm pods (“barreiros”). If, on the one hand, the reservoirs can store a large water volume, they face some issues: great evaporative loss, loss of storage capacity by silting, and distance from the point of use as they are often located in private areas belonging to third parties which prohibit or restrict access. The use of underground stocks is limited, traditionally through the construction of “cacimbas” and “cacimbões” (shallow dug wells excavated in the dry bed of rivers and streams), and water from confined aquifers is rarely used by family farmers. Only public investments and a few farmers have the economic resources for accessing deeper underground water sources.

During the 20th century, different administrations undertook actions to tackle the problem, from investments in water infrastructure to agricultural development based on the green revolution’s technological package. None of them resulted in consistent change in the overall context of vulnerability. As a reaction to the governments’ top-down approaches towards smallholder farming, a bottom-up approach called Human Coexistence with Semi-Aridity (HCSA) emerged in the early 1990s. Since then, it has been mainstreamed in regional governance, converging towards a sustainable development (SD) agenda. Its core technological paradigm is to “stock in abundance to cope with scarcity of resources and environmental variability” [1,5].

HCSA covers a wide range of strategies to cope with water scarcity in human and agricultural systems, but its technological core comprises RWH methods, many of them improvements of traditional ones. RWH is defined as any human interventions for locally collecting and storing rainfall for different human activities [6]. It can be classified between in situ and ex situ systems. The former refers to systems which retain rainwater in the topsoil while the latter covers systems that use a storage component (e.g., tank, dam) to divert the rainfall and run-off from the drain basin and store it for future use [7]. Ex-situ RWH can be further classified in sub-categories, of which two are relevant to the present paper: domestic RWH (DRWH)—when the water is locally captured through rooftops or other types of surfaces and stored in-built reservoirs for domestic use—and infield RWH (IRWH)—when the rainwater is harvested, stored and used in the rainfall collecting area, frequently for agricultural purposes [8,9]. The decision on the best RWH system is made accordingly to the purpose of storage (e.g., agriculture, groundwater recharge, aesthetic use) and is site-dependent, which can be decided based on a set of criteria: altimetry, topography, distance from the rainfall collection, dam height, etc. [10–12].

However, HCSA is more than a technological package. It is also a perspective on family farming’s SD in the SAB, characterized by a decentralized and participatory governance model [5] and by a contextualized education (CE), which reflects and problematizes the Semi-Arid’s environment, valuing the experimentation, the traditional culture and practices in the learning process [13]. As such, HCSA is simultaneously a technological paradigm, a SD discourse and a political and governance experiment in large scale, as it has been institutionalized through public policies in the SAB. Although HCSA has become well known in the Brazilian public debate context, it is still underrepresented in English literature, which makes publications on the topic relevant for the broader international debate of coping with semi-aridity. The present paper aims to contribute to this debate. To do so, we first present a historical evolution of the governance agenda based on the paradigm of “fighting against droughts” towards the concept of HCSA. Second, the results of an empirical research are presented and discussed. They are based on two case studies undertaken in the SAB, between 2011 and 2013, during the onset of the worst drought in the last 60 years. It shows that HCSA’s RWH technologies diffusion was influenced by a complex political-institutional context and social transformation in the SAB since late 1990s, bringing insights on RWH technologies implementation and governance challenges. Finally, the paper explores the synergies between the HCSA’s water technology and sustainable development goals (SDGs), highlighting potential links in the effort to position HCSA as a relevant SD discourse in the SAB and in other semi-arid contexts.

## 2. Coping with Droughts Agenda in the Brazilian Semi-Arid Region

The SAB is a political-climatic territory delimited by an average rainfall of less than 800 mm per year, an aridity index lower than 0.5 and drought risk higher than 60% [2]. Evaporation rates are high, ranging from 1000 mm to 3300 mm per year [14]. The rainy season lasts three months in average, and is concentrated in the summer months (December, January and February). Annual and seasonal patterns of rainfall are irregular. Years with precipitations well above the average are interspersed with ones much lower [14,15]. “Drought” is a broad term. From a meteorological point of view, a large drought is characterized by a marked reduction (more than 50%) of annual precipitation in relation to normal precipitation [16]. From an agricultural perspective, it means a poor distribution of rainfall during critical times of cultivar development and forage growth [14,17]. From a human point of view, large droughts marked episodes of hunger and water scarcity, and in the SAB, they contributed to the decline of regional economic cycles [17–19].

Until the 18th century, the Portuguese colonial administration—unable to make itself present in the large Brazilian colony—used the power of local economic groups over whom it had little authority in exchange for political legitimacy [20]. The production system was based on the binomial latifundium-minifundium—the former produced for the market, and the latter guaranteed the subsistence of the local families. A mixture of quasi-feudal domination and paternalism served as the foundation of the prevailing social system—the low-density family farmers lived and worked on the rural elite’s cattle ranches. The diversity of humid microenvironments scattered across the large properties provided adaptive alternatives for the rural population to cope with incidents of extreme drought events.

In the 19th century, the land exclusion resulting from the Land Law (1850)—together with the expansion of the cotton industry—caused the rupture of the historical production system, reducing the adaptive routines traditionally accessed by small farmers during dry years [21]. The great drought of 1877–1879 was the first to reflect the new land context, marked by both a large influx of refugees from impoverished rural areas to regional urban centers and the deaths of hundreds of thousands of people from hunger and diseases [18,22]. The human impact repercussions brought drought to the political agenda and triggered a model of government intervention based on large hydraulic works, the confinement of refugees in temporary concentration camps, and government aid in exchange for work in infrastructure works, known as “emergency fronts” [17,22–24]. Under the auspices of the state, dams and reservoirs were built, often on private estates; on the one hand, they ensured the availability of water; on the other, their distribution was used as a tool of corruption and domination, giving rise to the so-called “drought industry”, which thrived by shifting the blame of social and historical causes of misery and inequalities to rainfall irregularity [25].

In the early 1950s, there was an important shift in the way the state understood the SAB and dealt with droughts. It moved from a hydraulic focus to a developmentalism approach, acknowledging the underlying socioeconomic causes of poverty, hunger, and refugee influxes [26,27]. In agriculture, high productivity systems and irrigation poles close to water sources were fostered [28]. The federal government sought to direct modernization through the system of credit, cooperatives and rural extension linked to the green revolution technological packages, which were ill-adjusted to local culture [29]. Traditional subsistence crops—such as maize, beans, and cassava—lost area. The economic boom development and prosperity observed in limited territories [30] were accompanied by an increase in inequalities between the few who had access to opportunities and the majority who were excluded [31]. The logic of associating government aid and refugees’ work continued under the “emergency fronts”, common between 1970 and the end of the 20th century [24,32]. Episodes of famine, water insecurity and increased numbers of drought refugees during drought years remained until the late 1990s. There were several causes for the failure of state interventions in reducing drought vulnerability during that period: the concentration of water resources, land exclusion and the governments’ top-down approaches, following a developmentalism logic and often importing alien models being ill-adapted to the SAB’s environmental and culture particularities.

In the early 1980s, the SAB's civil society started a reaction against the conventional governance model to cope with droughts [5]. Along with the end of Brazilian military dictatorship (1964–1985), a period of re-democratization followed, in which new social and political actors appeared. This period coincided with the international emergence of the SD discourse, along with two important international conferences held in Brazil: the ICID (International Conference: Climate, Sustainability and Development in Semi-Arid Regions) and UNCED (United Nations Conference on Environment and Development). Such a context catalyzed an ongoing organization and articulation process, led by organized civil society and EMBRAPA (Brazilian Agricultural Research Corporation), towards a political agenda on family farming in the SAB in tune with the debate on SD. The development of the paradigm HCSA is inseparable from this process, synthesizing and driving the sector's agenda in a discourse aiming to mainstreaming it in a broader governmental agenda [26].

In 1992, the ARIDA's Project (1992–1995) was launched, in which many of the principles of the HCSA were contemplated. In 1993, during a severe drought, the Northeast Forum was created—an important milestone in the process of the socio-political deconstruction of the “fighting against drought” paradigm, opening space for the HCSA discourse to emerge strongly [33]. In the early 2000s, the paradigm had already defined its contours and begun to be institutionalized into governmental structure through public policies. This process is strengthened during the Brazilian Worker's Party administrations (2003–2016): family farming was institutionally separated from agribusiness, having a ministry of its own (Ministry of Agrarian Development—MDA), while rural credit, technical assistance, and diffusion of HCSA's technology policies were amplified. At the same time, cash transfer and emergency programs expanded in the SAB.

Between 2012 and 2017, a sequence of dry years devastated the SAB, bringing rural resilience to the extreme. Along with the general policy context, the HCSA's rainwater harvesting technologies played a key role. The magnitude of the human impacts reduced significantly, although food and water insecurity are still a reality to a lower degree and agricultural losses continued to be a reality [34,35]. However, since 2014, the Brazilian political-institutional and economic crisis impacted the agenda in the governmental sphere. The public budget for family agriculture dropped substantially and key institutions lost their strength, such as the MDA, downgraded to a secretary in 2016. Nevertheless, as a political discourse and technological paradigm, the HCSA is consolidated at the core of the debate on coping with drought in the SAB.

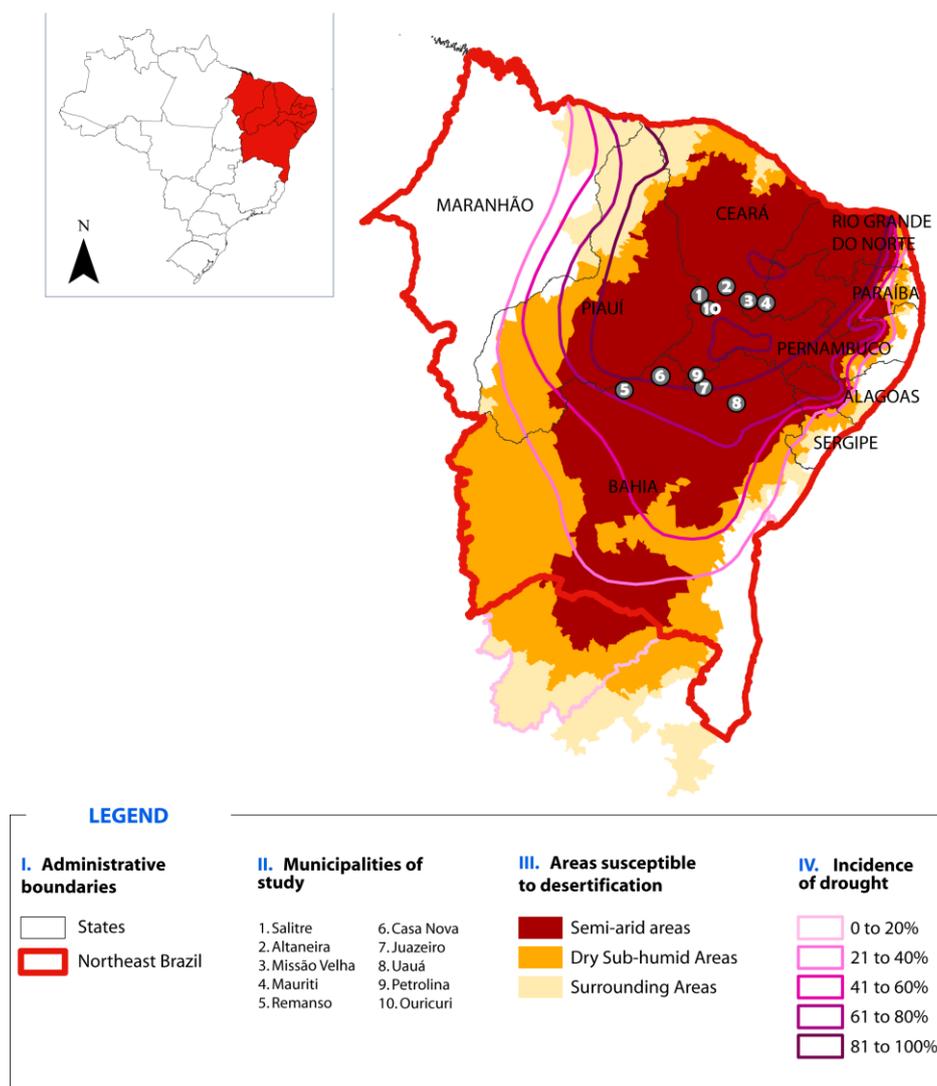
### 3. Methodology

#### 3.1. Case Studies

From an environmental perspective, water availability in the SAB is determined by both precipitation pattern and geological heterogeneity. Roughly speaking, the SAB is a mosaic of crystalline and sedimentary soils [36]. The former is shallow and poorly permeable, showing low percolation, so that precipitation evades as surface run-off. This explains the high number of intermittent rivers/streams and the scarcity of natural reservoirs during the dry season [37]. The underground stocks under crystalline soils are few and scattered, located in isolated fractures or cracks, generally providing low quality salty/brackish water [36]. By contrast, sedimentary soils are porous, common in the SAB's alluvial and sierra areas, presenting high water percolation and abundant underground deposits of good quality. In comparison to crystalline soils, sedimentary ones are not conducive to the formation of superficial reservoirs. Two case studies in the SAB covering both types of soils and within areas of elevated drought risk (Figure 1) were carried out with the objective of qualifying the main water technologies of the HCSA paradigm. In total, 499 rural establishments were visited and 32 institutional stakeholders were interviewed.

The first case study was carried out in the state of Bahia (BA), between June and July 2011, during the early dry season. It covered the rural area of four municipalities within the São Francisco river basin—two upstream of the Sobradinho Dam (Remanso and Casa Nova), and two downstream

(Juazeiro and Uauá). The region features predominantly crystalline soils and is a mosaic of different environments, and agricultural activities cover irrigation poles, floodplain cattle ranching, and rain-fed family farming.



**Figure 1.** Case studies location within Brazil and the Semi-Arid region of Brazil (SAB).

The second case study was carried out in the state of Ceará (CE), in the *Araripe* region, situated on a relatively humid sedimentary basin. In total, four municipalities were visited: Salitre, Mauriti, Missão Velha and Altaneira (Figure 1). The family farming households were scattered across sedimentary areas of sierra—higher, and with denser and more humid vegetation (Cerrado savanna)—as well as in low areas—on shallow and rocky soils, with drier vegetation (Caatinga) and a semi-arid climate. The fieldwork took place between November 2012 and January 2013, and this period coincided with the first-year of the dry-year sequences. Both case studies are located within areas of high incidence of droughts (Incidence of droughts is an indicator officially used by Brazilian government to assess the risk of drought during the raining season in any given area of the SAB [38]) (61–100%).

### 3.2. Data

The primary data was obtained from two sources, the first being semi-structured interviews with institutional stakeholders working locally with policies related to family farming (11 in Ceará and

14 in Bahia). Furthermore, a key stakeholder in the creation of the One Million Cisterns Program (P1MC) and five researchers of EMBRAPA's Semi-Arid unit (EMBRAPA's Semi-Arid unit is located in Petrolina city, Pernambuco (Figure 1) and participated in or is responsible for developing most of the technologies discussed in the paper) were interviewed (Figure 1). Finally, the observations during two-day field work of a local HCSA's NGO was undertaken as well as one of its staff was interviewed in Oricuri municipality (Pernambuco), in August 2012. The semi-structured interviews allowed us to understand the functioning mechanism, difficulties and potential of the HCSA's water harvesting technologies from the frontline perspective. Furthermore, given the broad knowledge of the local farming context, the information obtained was paramount in qualifying the HCSA panorama in the case studies.

The second source of primary data originated from interviews conducted with 499 family farmers—249 in the municipalities of Bahia and 250 in Ceará. They were conducted by an interviewer from an interdisciplinary group of researchers (both social and natural scientists), who received training beforehand in order to assure a standard technique. Interview subjects covered productive activity and hydric security and lasted from 20 to 60 min. The sampling method was an adapted version of the transect walk method [39]. The transect walk usually consists of group walking along a linear transect for a set period of time. The adaptation replaced walking on foot by car displacement, following the gravel and sand roads in the rural areas. In order to avoid major selection bias, properties were chosen randomly by visiting one every  $n$  found,  $n$  ranging from one to three according to the size of the rural community. One person per household selected was interviewed, mostly men. For data processing, software SPHINX IQ was used. Often the interview evolved into property visits and researchers undertook direct observations, photographic records, notes, especially regarding water harvesting technologies. Some of the interviews (29, 9 in Bahia, 20 in Ceará) became unstructured interviews where farmers' experiences and choices were discussed in depth.

Finally, secondary data was taken from the online databases of governmental agencies, regional and local civil society institutions, and scientific literature. The descriptive statistical analyses developed in this article are not aimed at producing generalizations for the municipalities or the SAB, and conclusions are restricted to the sample. Our mix-method approach combined with the extensive literature review, however, allowed us to understand underlying conditions that generated such answers.

## 4. Results and Discussion

### 4.1. The HCSA's RWH Technologies and Family Farming in the SAB

The interviews, transect walk observations and literature allowed the identification and characterization of the main strategies to cope with water scarcity in case studies, including the HCSA's RWH technologies. The field research examined their relevance in local contexts and gathered elements to qualify their adaptive potential and implementation process in loco. The results are shown in Table 1 and discussed below.

The slab cistern is the HCSA's flagship technology. It is a DRWH system, and the most widespread water technology in the case studies (Table 1) and in the SAB's in general [40]. However, until the early 2000s, they were rare in the region. The context changed in 2003, when the concept became a government policy under the name One Million Cisterns Program (Programa 1 Milhão de Cisternas–P1MC). The governance model was based mainly on public funding, and the implementation process conducted by local NGOs [40]. An OSCIP (Civil Society Organization of Public Interest) called ASA (Articulation of the Semi-Arid), created in 1999, was responsible for the coordination of a decentralized management system. The program became a new institutional experience in Brazil: a cooperation between civil society and government in the management, conception, and execution of projects based on public-private partnership, decentralization, political emancipation, and social mobilization [33].

**Table 1.** Frequency and descriptions of the main strategies to cope with water scarcity observed in the case studies of Bahia and Ceará (*n* refers to the total sample observations). RWH: rainwater harvesting; DRWH: domestic RWH; IRWH (in field RWH).

Technology to Cope with Water Scarcity	Frequency (%)		Strategy Description
	Bahia ( <i>n</i> = 250)	Ceará ( <i>n</i> = 249)	
Slab Cistern (DRWH)	68	29	The houses' roofs are adjusted to capture rainwater. The water is transported by gutters, and stored in cisterns with a capacity of 16,000 L, adjacent to houses (Figure S1). The slab cistern aims to provide potable water to meet the basic human water needs (drinking and cooking) of a family up to six people during the dry season, which may last 6–8 months [40]. The water quality would be guaranteed by the proper management of the harvesting—storage system, as well as by the addition of chlorine tablets or equivalents.
Production Cistern (DRWH)	7	0	It consists of a 52,000 L concrete tank, covered on top, partially underground, and connected to a concrete patio (210 m <sup>2</sup> ) to harvest rainwater. The patio is frequently used to dry the crops. The production cistern's water is used to keep small gardens and productive backyards for family consumption, and exceptionally, for quenching the thirst of domestic animals. Eventually, the surplus is marketed.
Stone tank (IRWH)	5.6	0	The technology increases the natural capacity of rocky cracks and holes to harvest rainwater run-off by building walls in the lower part or around the reservoirs.
Underground dam (IRWH)	0.5	0	It consists of building impermeable, subsurface vertical septa at specific points into the river bed. The blockage raises the water table level, increasing the volume of retained water upstream, resulting in the concentration of micronutrients and creating a humid and fertile area for subsistence crops and orchards [41]. Experiments in the SAB show that the cultivated area can reach 1 ha and sustain a diversity of crops, such as maize, beans, cassava, squash, fruit trees, forage crops, etc. [42].
Trench dam (IRWH)	0	0	Trench dams are long and narrow reservoirs excavated into the soil. The bottom and the walls are covered by a tarpaulin, the storage capacity is up to 150,000 L, and its shape and coverage substantially reduce evapotranspiration losses.
Dam for Supplemental irrigation (IRWH)	0	0	It is based on two interconnected rainwater storage tanks. To reduce evaporative losses, the second tank is only filled after the first tank is completely full. Both tanks are built in a small drainage basin, in high ground next to the agricultural systems, in order to eliminate the cost of water transport. The storage capacity reaches 8 million liters, sufficient for supplemental irrigation of up to 4 ha [43]. Supplemental irrigation provides just enough water to increase rain-fed crops productivity during the dry season or long dry periods between episodes of rain during the rainy season [44]. Instead of optimizing productivity, the goal is to achieve “good enough productivity” for domestic consumption, along with some surplus for selling.

Table 1. Cont.

Technology to Cope with Water Scarcity		Frequency (%)		Strategy Description
		Bahia (n = 250)	Ceará (n = 249)	
In-situ RWH	Soil Conservation Strategies	0	0	Comprises different methods like creating physical barriers in the agricultural plot combining plowing practices in building channels and ridges between crop lines, prolonging water retention in the root zone [37,45]. The HCSA approach also encourages post-harvest agricultural waste disposal on the soil, reducing evapotranspiration losses, erosion, and soil compaction. The productivity increases and the extension time of moisture levels may be key for crop resistance to long dry periods in between rainy periods [44–46].
Other	Drilled wells	0	48.6	Community wells drilled—usually through public policies—to access confined aquifer’s water.
	Prickly pear cactus ( <i>Opuntia</i> sp.)	75	1.2	Very well adapted to the SAB’s dry climate, the cactus stores a high amount of water in its tissues [47]. The supply of <i>Opuntia</i> sp. in animal feed reduces the daily herds’ water demand, acting indirectly as a water source for livestock.

\* n = 175 (farms with livestock); Source: elaborated by the authors based on literature and field research.

The Brazilian Federal Government estimates that between 2003 and 2016, 1.2 million rainwater harvesting cisterns for human consumption were implemented [48]. The beneficiary families are part of the Single Registry for Social Programs (Cadastro Único para Programas Sociais), aimed at families considered economically and socially vulnerable in Brazil. Families offer a counterpart, such as digging the ground where the cistern will be built and providing a work aide, as the goal is to engage them in the process and strengthen the sense of ownership. It has been verified in both case studies that the masons were usually local residents, trained in the construction of the cisterns, which contributes to the generation of income to areas where economic dynamics are low. Until recently, the implementation of a cistern was accompanied by training on water resource management, living with a semi-arid climate and citizenship [13]. However, in 2014, ASA lost the monopoly in managing the P1MC's implementation, which can now also be done by local administration. These do not adopt the obligatory training, and are also installing plastic cisterns, of inferior quality.

One of the founders of the program—interviewed in the research—explained that the overall goal was to increase the resilience of family farmers, reducing the rural exodus and demobilizing the drought industry. The expectation was that the slab cisterns' diffusion would decentralize water access and enhance the smallholder farmers' autonomy. Historically, the water sources used in the SAB for human consumption were often of poor quality, brackish, and shared with animals. The incidence of gastrointestinal diseases was high, and the displacement of families to fetch water, usually done by women and children, often took several hours for a small volume of return. A common perception shared by local institutional stakeholders interviewed was that the P1MC represented a great leap in rural life standards and weighed positively on keeping the population in the countryside. There were also reports of elderly people returning to rural areas, decades after they had moved to urban centers—once retired, they felt encouraged by the improvements in rural life comfort. Such a phenomenon is not due exclusively to slab cisterns, but they are an important part of a broader process of improving infrastructure and income in the rural SAB.

However, what stood out during the field research was the fact that slab cisterns were being used in ways others than the ones foreseen in the program's design. First, families often used water in domestic activities other than cooking and drinking—bathing, hair washing, teeth brushing, house cleaning, and, occasionally, in some productive activities, such as animal fodder and vegetables. This “misuse”, from the perspective of the program, must be understood within a broader context. One factor is that, given the gain in the quality of life standards and the relatively low cost in building a slab cistern (US\$ 1000), many farmers decided to build a second cistern on their own. A second factor was the increase in the availability of water tankers for rural water supply. The economic boom during the 2000s, much associated with government programs of cash transfers, loans, and pensions, significantly increased the economic dynamics and income in the rural SAB. During this period, many producers were able to hire water tankers to supply slab cisterns, relying less on rain or other sources. In a sense, as observed in the case studies, cisterns functioned as a rural water containers.

Therefore, more significant was the implementation of the governmental Emergency Water Distribution Program (Programa Emergencial de Distribuição de Água) or “Water Tanker Operation”. The program was planned to be temporary and in response to the 1998 drought in the SAB. However, it has been consolidated as a perennial government policy—even though it has remained officially an emergency program—acting informally as a rural water supply service, using P1MC cisterns as the preferred reservoir. In 2016, it served about 4 million people in the SAB and had a budget of approximately US\$ 300 million, which indicates a favorable cost-benefit ratio of around US\$ 75 per person [48].

Evidence from the field research indicates that local politicians may have been supplying water tankers in exchange for political support. Such observations were especially common in Bahia's case study, which occurred during the year prior to municipal elections. Other authors [22,49] support the hypothesis of eventual political use of the HCSA's water technologies, including the combination of water tankers and slab cisterns [50]. If corroborated by further research, it may reveal a retrofit in some

degree of clientelism-type relationships, similar to those observed in the “drought industry” time, but with different stakeholders and nature of relationships.

The slab cisterns were designed mainly for human consumption, but most of HCSA’s RWH technologies focus on agricultural systems, especially the production cistern (Figure S2a). At the time of the research, in 2012, the technology was in its early diffusion in the SAB, but recent reports show that about 160,000 were built in the region [48]. As an example, one of the family farms visited in Remanso (Bahia) maintained a productive area of 150 m<sup>2</sup> with a production cistern, in which vegetables, tubers, a small orchard, and fodder for the sheep/goat herd were produced (Figure S2b). The great advantage of the production cistern is its viability in virtually any terrain. In addition to the potential benefit and relatively low cost (US \$3000), the production cistern also became a governmental policy named “One Land, Two Waters Program” (*Uma Terra, Duas Águas*, P1 + 2), based on the access to plots for agriculture and two water sources: one for human consumption (slab cisterns), and another for production. The P1 + 2 program was based on the experience of the Program 1-2-1 (one land, two human consumption cisterns, one production cistern), implemented in the Chinese semi-arid region in the 1990s and with equivalent programs elsewhere worldwide [51,52].

Local NGOs and EMBRAPA also develop other methods to harvest run off, the most prominent among them are the IRWH systems trench dams (“barreiros lonados”), stone tanks and dams for supplemental irrigation (Table 1). The ancient practice of planting in the bed of intermittent rivers was improved as well, taking advantage of the humid soil provided by the proximity to the water table. The HCSA’s improved version is the underground dams, a RWH technique that increases the groundwater level for agriculture. However, in the case studies, they were rare (Table 1). Finally, different soils conservation methods (in situ RWH) were adapted for the SAB. They were mentioned by EMBRAPA’s researchers interviewed and in literature [44–46,48] as adaptive strategies in deficit rainfall contexts, but were not observed in loco (Table 1).

The water security of livestock systems is also a challenge in the SAB. Usually, families’ agricultural income depends on cattle, goats and/or sheep ranching. The herds have high water demands—one goat or sheep requires 2–6 L of water a day (15 L if it is a dairy animal), and a bovine, 35 L (62.5 L for a dairy cow) on average [53,54]. Even relatively small herds depend on large and perennial reservoirs. In such a context, the most common water sources for livestock observed were the traditional ones, such as “barreiros” and dams. Where environmental conditions allow, water from perennial rivers, streams, and lakes is used. However, these resources are scarce in the SAB region, and unevenly distributed. They were not central in the case studies, apart from among ranchers who were able to move their animals to the banks of the São Francisco river (in Bahia’s case study) or to the banks of the Salgado River (in Missão Velha, Ceará).

The HCSA’s RWH technologies described above were eventually used in animal watering, but were hardly enough to fulfill the herds’ needs. In this context, the use of the Prickly Pear Cactus (*Opuntia* sp.), one of the forage strategies disseminated by the HCSA, is noteworthy (Table 1). Its cultivation was very common in Bahia’s case study, found in 75% of establishments where there were herds in (Table 1). In contrast, the cactus was rare in Ceará, accordingly to the interviewees, because the sierra’s sedimentary soils are not adequate for the plant; there is a high resistance of farmers in adopting it and the decline of Prickly Pear Cactus cultivation because of agricultural plague in the past.

The overall results show the HCSA’s strategies to cope with water scarcity in the SAB target human and agricultural use. Most of them are RWH methods and all of the ex-situ RWH—except stone tanks—store water in covered reservoirs, tackling one of the most sensible aspect of traditional storage methods: evaporative losses. However, their diffusion rates differed substantially among them and between case studies. The slab cistern frequency stands out in both case studies, which could be explained by the fact that their diffusion was under a governmental program (P1MC), with substantial and consistent funding and was ongoing for a relatively long time at time of the research (10 years).

Additionally, the training of local masons and low cost in building a slab cistern made the technology easily spontaneously reproduced by the rural population.

P1MC success can also be explained by the decentralized governance model in which local institutions had a protagonism, especially in Bahia's case study, where a well-organized and active civil society is behind the diffusion of the technology. The reasons underlying a relatively lower adoption rates in Ceará's case study are not clear and further research is needed, but our cases comparison points to the absence of local NGOs and a significant number of households with access to drilled wells in rural areas as some of the reasons. It was expected that production cisterns would present high frequency, once it is also under a governmental program (P1 + 2) and it is implemented in a similar governance model. However, P1 + 2 was in its early implementation stage at the time of the field research, plus it is a more expensive technology.

The other HCSA's RWH technologies identified were not common, despite their high adaptive potential. The reasons are many. First, environmental limitations play a key role in some of them. Underground dams, stone tanks and dams for supplemental irrigation demand very specific environmental conditions that are unevenly distributed in the SAB. It is the case of Ceará's sierra areas, where, on the one hand, both the high percolation rates and depth of sedimentary soils associated with predominantly flat terrain were not suitable for such technologies. On the other hand, abundant aquifers in these areas allowed access to underground water through drilled wells manufactured by governmental interventions.

There are also important economic barriers related to the high financial, labor and machinery costs necessary for implementing them in an impoverished rural population. The few observed were only found in households that were part of pilot projects carried out by research institutions or received special support from governmental and NGOs' projects. The limited capacity of these institutions in providing technical service and supporting the technologies implementation by themselves beyond small groups of farmers is also responsible for the few observations of such technologies in case studies.

Furthermore, farmers' preferences also stood out during the interviews as a factor for low adoption rates of some of the technologies. First, interviewees expressed resistance and mistrust for novelty in the traditional way of farming. Second, they mentioned that interest in adopting a new technology is proportional to a tangible benefit: while the water access provided by a slab cistern is quite tangible, the benefit of RWH in agricultural systems is not so clear and direct, once the cost-benefit assessment goes beyond the increase of resource availability. It also includes the income return considering the labor, time and economic costs to implement the technology. It was a common statement among stakeholders that access to market is a central issue for commercializing the farm's products. The profits are usually low, which may influence in decision about adopting a more elaborated and costly technologies, at least without external financial and technical support.

The RWH methods to cope with water scarcity discussed in the paper are widespread globally and have being developed and adapted in many other semi-arid contexts [44–46,55–58]. In this sense, HCSA does not represent a technological novelty in comparison to other initiatives around the globe, even though the technological adjustment to the local environmental context of the SAB bear some creativity in its solutions. What makes HCSA approach unique is the underlying historical process of paradigm shift brought up by civil society and research institutions, which had induced the mainstreaming of the RWH technologies into a governance model despite the difficulties of scaling up the full range of strategies observed in the case studies.

#### *4.2. The Human Coexistence with Semi-Aridity and the Sustainable Development Goals*

The HCSA paradigm converges with the SD discourse, often using points of convergence to gain legitimacy on a broader development agenda. It is no coincidence that their agenda has developed in parallel, reflecting and being reflected in the SD debates during the 1990s and 2000s. The HCSA's water harvesting technologies discussed in this paper are cross-cutting the current (2018) debate on

SDGs [59], with great potential to contribute positively in achieving them, not only in the SAB, but also in other semi-arid regions worldwide.

The family farming food security depends on agriculture. Great droughts usually represent crop failures, loss of livestock, and inflation for both food prices and farm input costs. The impact on income and food security is not only short-term, but also has medium- and long-term effects as households are forced to sell assets or to get loans with disadvantaged conditions. The HCSA's water harvesting technologies increase the resilience of agricultural systems, and can be decisive in keeping minimum productivity for self-consumption and commercialization, converging to SDGs 1 and 2, Zero Hunger and No Poverty, respectively.

Slab cisterns have substantially reduced the distances and time spent on fetching water, contributing immensely to a better quality of life for women and opening up new occupancy and development opportunities, in synergy with SDG 5, Gender Equality. At the same time, the most obvious benefit of the slab cisterns—to provide clean, affordable water at the family level—directly tackles SDG 6, Clean Water and Sanitation. Evidence points out that slab cisterns may be contributing to the control of waterborne diseases in the SAB [60]. They also contribute towards SDG 10, Reduced Inequalities, not only by addressing water safety, but also by decentralizing access to it.

The HCSA's participative and decentralized management governance model is in tune with SDG 16, Peace and Justice Strong Institutions, and especially with target 16.7, which calls for inclusive, participatory, and representative decisions at all levels. The HCSA's contextualized education guidelines is transversal to SDG 4, Quality Education, and in particular to target 4.7, which claims for education to ensure knowledge and skills for sustainable livelihoods, valuing cultural diversity and cultural contributions for SD [59].

In situ run-off harvesting methods and other soil and water conservation techniques converge towards SDG 15, Life on Land, which one of its targets is to fight against desertification—one of the main processes of environmental degradation in the SAB. Furthermore, the HCSA's water technologies in general relate to the mitigation and adaptation targets of SDG 13, Climate Action, and in particular the high adaptive potential, which can be articulated within a framework of responses to reduce sensitivities and increase adaptive capacities of vulnerable populations in the SAB likely facing more extreme climate scenarios of drought in the coming decades [4].

## 5. Conclusions

The conclusions point out that, on the one hand, HCSA's research and innovation system were successful in developing and adapting a local appropriate and advanced RWH technological package for coping with drought and seasonality at small scale. On the other hand, they haven't scaled up in case studies, except for slab cisterns. Despite the highly adaptive potential, the other HCSA's RWH technologies were limited by environmental barriers, implementation costs and low institutional capacity. The slab cisterns case suggests that the institutionalization of the technologies under a governmental program cooperating with local civil society might be key to boost their diffusion in rural areas. This case studies also led to another conclusion: the dissemination of a technology is not always straightforward, accordingly to initial policy design. The P1MC showed that the policy implementation partially diverted from the original concept of storing rainfall for drinking and cooking, and took unexpected sources and ways of uses as it interacted with a wider context of policies, institutions and social transformation in the SAB.

"Drought", aside from being a climatic phenomenon, is a political narrative which has been used by different stakeholders in the SAB, at different times, either to justify developmentalism models or to seize power structures. The HCSA subverted this narrative and presented another, which has radically transformed the discourse of the struggle against a relentless nature into one of adjustment to a given environmental context. Rather than being inhospitable and having the climate as the enemy, the Semi-Arid region is understood as a source of productive opportunities where high quality life standards are feasible. In order to reach such opportunities and high standards, it is necessary to

engage in synergic relations with local ecosystem resilience—instead of fighting against, coexistence is the key.

The HCSA presupposes deeper reflections on the role of rural family production in the SAB and its economic vocation. High-performance, input-intensive, and market-oriented productive systems have been historically the benchmark of the Brazilian agricultural sector, and are at the desired extreme of a scale of progress in which low-income family systems are perceived as synonymous with backwardness. The Coexistence paradigm has also subverted this narrative of agricultural development, and advocated for a less intensive model of inputs, of suboptimal productivity, aimed at self-consumption and income generation, which favors the pluriactivity and multifunctionality of establishments. The economic focus on production has been broadened to a multidimensional perspective, consistent with the notion of sustainability: beyond production and income, the paradigm is based on the value and continuity of the socio-cultural system which has been developed by the SAB's rural populations for centuries.

The HCSA seeks both a retrofit of the traditional system, updating it to a reality in the accelerated change of the early 21st century, as well as greater political protagonism of local civil society in its own future. Adding complexity to challenges ahead, demographic trends in the rural SAB—such as the migration of young people to the cities and the aging of the rural population—increase uncertainties around the continuity of the traditional basis of family farming in the region. Furthermore, more extreme and prolonged droughts or even totally new environmental conditions never experienced before are expected to come with climatic change. Such scenarios will push adjustments and innovations of the HCSA's technologies already available. In that sense, HCSA will never be a finished product—rather, its potential is tied to its ability to learn and evolve according to new information and contexts. For family farming in the SAB, change is the only certainty ahead.

**Supplementary Materials:** The following are available online at <http://www.mdpi.com/2071-1050/10/3/622/s1>, Figure S1: Slab Cisterns, Figure S2: Production Cisterns.

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