# Rainwater Harvesting in the Rainforest: A Technical and Socioeconomic Review of Community Approaches in Brazil

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**Abstract.** This paper reviews potable water issues affecting river dwelling communities and assesses the use of Rainwater Harvesting techniques to help meet potable water requirements. The study specifically explores river communities on the periphery of the city of Belem, where there is no potable mains water supply. This interdisciplinary study reviews the socioeconomic context of the different organisational stakeholders as well as analysing technical data to ascertain the effectiveness of the systems in practice. Surveys indicate nearly half of residents consume water from sources potentially contaminated by raw sewage and mining effluent with detrimental impacts to public health. This paper reviews previous local studies and describes on-going attempts to derive locally appropriate rainwater collection and treatment processes. This includes attempts to construct and trial organic material-based rainwater filters that comprise of different mixes of sand, gravel and activated carbon derived from by-products of local fruit processing industries, namely acai harvesting.

**Keywords:** Rainwater Harvesting, Peripheral communities, Water filtration, Governance.

## 1. Introduction

This study explores the water issues affecting river island communities in the Amazon region of Brazil, and on-going attempts to assess the viability of employing Rainwater Harvesting techniques and locally sustainable filtration methods using organic materials to help meet local water requirements. The study specifically considers river communities on the periphery of the city of Belem (Figure 1) in the State of Para. Belem's municipal area includes a number of inhabited river islands – the total population of the city is estimated to be 1.45 million [12], whilst the population of the surrounding river-dwelling communities, known in Portuguese as 'Riberenhos', was reported at 3049 in the 2010 census.

Belem municipality experiences a range of significant water and sanitation challenges. For example, only 59.9% of the city's population are connected to the mains clean water supply [3]. In terms of sanitation, Bland [3] reports that only 6.3% of the city's population are served by a sewer network and that the vast majority (95%) of Belem's raw sewage is pumped into surrounding rivers, Guamá and Tocantins. Some of this river water is abstracted for drinking supplies by surrounding communities [9][21]. Belem experiences Brazil's highest rates of hospitalisation due to diarrhoeal diseases for children under the age of five (Fundacao Abrinq, 2018). In addition to the direct public health impacts, these issues lead to wider economic pressures: the lack of sanitation in one of Belem's neighbouring districts (i.e. the municipality of Ananindeua) resulted in R$19,5 million (approximately US$5.1 million) of medical care costs between 2007 and 2015 (Globo, 2017).


**Figure 1:** Inhabited river islands around the City of Belem in Brazil's Para State.

## 2. Background context

### *2.1. Sustainable Development Goals*
The United Nation's Sustainable Development Goal 6 (UN, 2010) aims to ensure access to water and sanitation for all, stating that lack of access is partially attributable to economics or poor infrastructure. These factors cause millions of people to die every year, many of them children, from water related diseases. The SDGs highlight the importance of integrated action to address economic, social, and environmental development. In this context, it is worth considering the range of organisations that play a role in relation to the supply of clean water within Belem.

### *2.2. Key stakeholders*
Complexities in Brazil's political structures impact the governance of water. Brazil is a Federal Republic, where the states, such as Pará, are autonomous sub-national entities with their own governments. The states are sub-divided into municipalities. Each municipality has an autonomous local government [4]. Different parts of this federal system dictate the legal aspects of water supply to communities in Brazil, organisations in water management exist at the federal and municipal level, for example, the ANA (National Water Agency) and SINGREH (National System of Water Resources Management – incorporates several institutions including ANA) [1]. The urban water supply in Belem is managed by Cosanpa (i.e. the Pará water and sanitation company), but this agency does not serve the river islands in the municipality of Belem [2]. Other organisational roles in the provision of clean water for Belem's island communities are highlighted in Table 2. These organisational relationships were previously reviewed by Cardoso-Castro *et al*. [5].

**Table 1.** Organisational roles linked to clean water provision on Belem's River islands.

| | |
|---|---|
| **Policy** | Federal Government (e.g. FUNASA – National Public Health Authority) |
| **Regulation** | Municipal Government e.g. AMAE – Water and Wastewater Regulator |
| **Research** | Federal University of Para; Federal Institute of Science Education and Technology |
| **Finance** | NGOs e.g. CARITAS; Federal Government e.g. MDS; State Government (SEASTER) |
| **Implementation** | Island Community Groups; NGOs e.g. CARITAS; State Government (SEASTER) |

### *2.3 Local water issues*
The vast majority of Belem's island communities are not served by mains water supplies or sewer networks [2]. It has been reported that this is partially due to their remote locations but may also have resulted from a lack of enforcement and enactment of Federal Government guidelines on water quality

for domestic supplies [13]. At the municipal level, Belem residents are not receiving the Federal standards of water [7][17]. The water company for Para state 'Cosanpa' is suffering financial problems (Fundacao Abrinq, 2017) stating that they are not currently able to make further investments to improve water infrastructure (Globo, 2017).

Communities are forced to rely on a range of alternate water sources including river abstraction. Previous studies [21][9] explored the different water sources used on two case study islands (Ilha Murutucu and Ilha Grande), through community survey exercises. These studies reported that 11.4% of residents on '*Ilha Murutucu*' and 5.7% on '*Ilha Grande*' were consuming water directly drawn from the river. It was highlighted in the previous section that this tidal river receives untreated sewage from the city of Belem [3]. This is a common occurrence, it has been reported that on average 86% of the sewage discharged from the cities in the Amazon basin is not treated (Fundação Abrinq, 2018). The river may also contain other pollutants, which have emanated from further upstream in the Amazon basin. For example, there are china clay mining activities in the adjacent municipality of Barcarena (Imerys, 2018) and waste spills emanating from bauxite processing at alumina refineries [11](Nathanson, 2018).

**Figure 2:** River-based vendors on the Amazon [9][2].

Veloso [21] and Gonçalves [9] highlighted that a significant percentage of the surveyed communities (i.e. 42.7% of residents on Ilha Murutucu and 42.9% of Ilha Grande) purchased jerry cans of water from river-based vendors (Figure 2). The containers of water sold by these river traders at a price of R$2.00 (US$0.52) are not considered to emanate from a clean source and often exhibit high levels of turbidity [10].

*2.4 Rainwater harvesting by river dwelling communities*

Almost half of the island populations surveyed by Goncalves [9] and Veloso [21] were reported to be consuming potentially contaminated water (e.g. sourced from the river vendors or abstracted from the river). In response to these challenges a range of previous studies [9][21][8][19] have sought to explore the merits of alternative water sources that are appropriate to this context, and less likely to be contaminated. Given that Belem has a wet season that lasts for 6 months per year [22], with rain continuing to fall during the dry season, Rainwater Harvesting has been considered as a viable alternative water supply.

Veloso [21] undertook community survey work on a number of river islands which indicated that between 50-61% of residents were in favour of using a RWH system. However, some were reportedly opposed as they did not like the taste of rainwater compared to the water they usually bought from local vendors. The study concluded that although RWH systems appeared to be both environmentally and socially viable, local residents could not afford to install the systems due to their incomes being lower than the minimum wage [21].

A separate exercise conducted by Dias [8] undertook a sustainability appraisal of RWH systems in the Amazon context using five indicators (Environmental, Social, Economic, Politico-institutional, Technical). This study suggested that the politico-institutional aspects of implementation were unsustainable despite the technical scalability of RWH [8]. More recently, Silva [19] sought to explore the quantity and quality of rainwater collected from these systems. This study attempted to define an efficient yet easily repeatable procedure for treating this rainwater [19]. Further studies have explored the merits of employing filter beds that utilise local materials to treat collected rainwater.

These RWH field-trials have compared water quality indicators from sampled raw (untreated) roof water, with water treated using a sand/activated carbon bed. The five common water quality indicators used in these tests are: pH; Turbidity; Colour; Coliform Bacteria; E. Coli. The Federal Government of Brazil standards set out by the Ministry of Health (2011) in Decree 2.914/11 are consistently referred to as the criteria required for potable water in Brazil throughout the studies this report has reviewed (See Table 4).

**Table 2:** Standards for collective systems supplying < 20,000 inhabitants, [13].

| Parameter | Recommended Maximum Value |
|---|---|
| **pH** | 6-9 for guidelines to be followed |
| **Turbidity** | 1 NTU across 95% of samples, to a maximum 5 NTU |
| **Colour** | 15 Hazen units |
| **Coliform Bacteria** | No more than 1 positive test per month permitted in structured testing routine |
| **E. Coli** | 0/100ml |

### *2.5 Application of locally sourced Acai as a water filter medium*
The acai palm is a tree species that is farmed across the Amazon region for its fruit, palm, leaves and wood. This activity generates a substantial amount of waste material. The acai fruit has a relatively thin mesocarp (~1mm thick) which is used for the fruit pulp. The majority of the fruit consists of the seed, of which large volumes are discarded as waste during processing. For example, Belem and Para State produced 706.488 tonnes of acai pulp in 2010, representing 86.9% of Brazil’s annual production [14](SAGRI, 2010). Acai harvesting and production is said to employ more than 25,000 persons directly in the north of Brazil, and constitute 70% of river island communities’ incomes [14](Lopez and Santana, 2005). Research into the use of activated carbon from fruit processing by-products, namely acai for filtration has been applied in various contexts in the removal of water contaminants such as dyes, sewerage and heavy metals by Brazilian researchers in recent years [18][17][16](Cunha *et al.*, 2012).

### *2.6 Review of previous water filter strategies*
A number of previous studies have investigated alternative filtering/treatment strategies that might be used by river island communities to improve the quality of water collected from RWH systems. These studies have explored the merits of various filters that comprise different mixes of sand, gravel and in three cases activated carbon from acai seeds. Figure 5 lists previous research carried out by local researchers in the state of Para (PA) and the state of Espirito Santo (ES) (i.e. with the use of a larger sand and gravel filter to supply potable water to isolated communities there).

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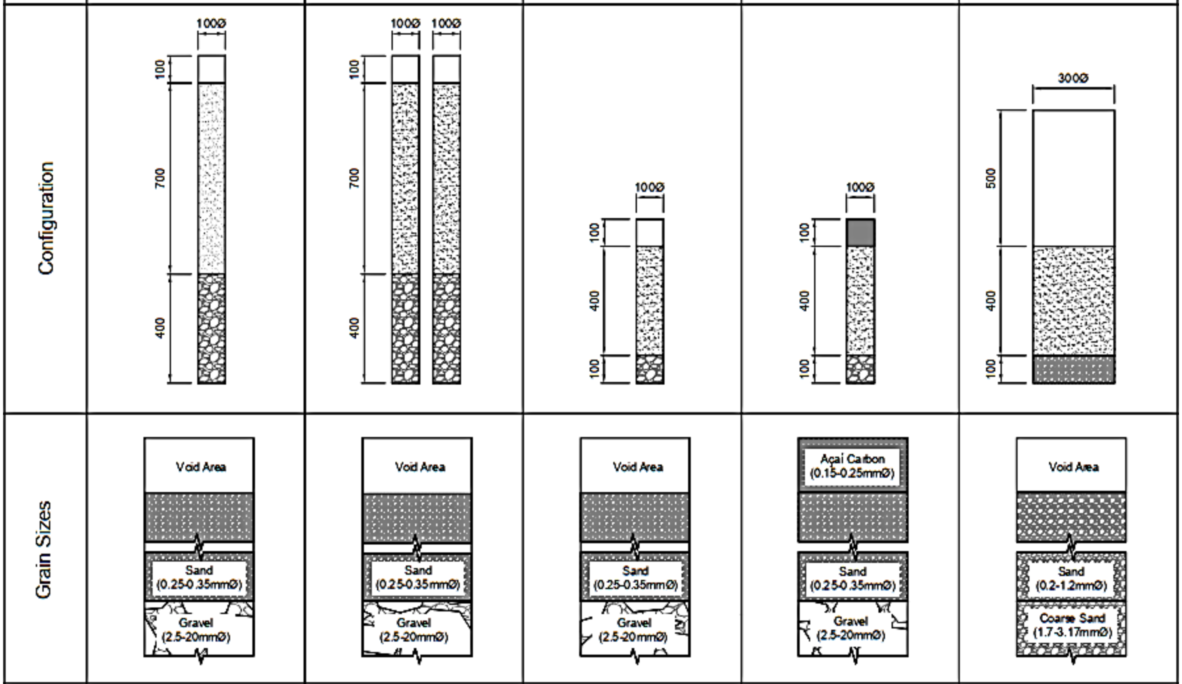
| Case | Filter Type 1 | Filter Type 2 | Filter Type 3 | Filter Type 4 | Filter Type 5 |
|---|---|---|---|---|---|
| Author | Goncalves (2012a) | Goncalves (2012a) | Oliveira et al (2017) | Cruz, Teixeira and Menezes (2017) | Goncalves (2012b) |
| Location | Ilha Murutucu, PA | Ilha Grande, PA | UFPA Belem, PA | Curio - Utinga, PA | UFES, Vitoria, ES |




| Sample Results | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Raw | Filtered | Raw | Filtered | Raw | Filtered | Raw | Filtered | Raw | Filtered |
| Turbidity (NTU) | 1.04 Median | 0.5 Median | 1.28 Median | 0.47 Median | 0-5.6 Range | 0-6.8 Range | 2.3 Mean | 0.5 Mean | 1.13 Median | 0.06 Median |
| Colour (HU) | 27 Median | 11 Median | 20.5 Median | 9 Median | 1-67 Range | 3-72 Range | 7 Mean | 0 Mean | 15.23 Median | 3.12 Median |
| pH | 5.5 Median | 5.4 Median | 6 Median | 5.6 Median | 6,4 Mean | 6 Mean | 7.5 Mean | 7 Mean | N/A | N/A |
| Coliform Analysis | E-coli present | E-coli present | E-coli present | E-coli present | 49.7% average coliform reduction in filtered case | | 41.6 coliforms NMP/100ml Mean | 4.8 coliforms NMP/100ml Mean | 262 E-coli NMP/100ml Median | 7.2 E-coli NMP/100ml Median |

**Figure 3:** Summary of publications investigating rainwater filter configurations in remote/peri-urban contexts in Brazil.

*2.6.1 Summary of findings from case studies 1-5*

Case studies 1 and 2 at the Federal University of Para [9] trialled two filter configurations on the islands of Murutucu and Grande. These filters used sand and gravel to treat water collected from tiled roofs. Units were installed in August and were in use from September. Fifteen water samples were collected during consecutive site visits conducted between January and April. Tests indicated that the filtered water was generally not of a potable standard without additional treatment using sodium hypochlorite, although reductions were achieved in turbidity, colour and pH. Case Study 3 at the Federal University of Para [15] explored the effectiveness of acai filters using a small sand and gravel filter tested on campus, which was new at first use with the materials disinfected with 2% chlorine bleach for 2 hours prior to assembly. 60 Sample sets were taken during March to August 2014 and 17 from October to January 2015. Results found minimal reductions in the tested parameters compared to the raw water case, and in some cases worse results post-filtration. It concluded sand and gravel filters alone were not effective for the filtration of water. Case Study 4 [6] constructed two similar rigs, to those in case study 1 and 2, in riverside communities in Belem using filters the same size as case study 3 but containing a mixture of sand and activated acai carbon. The units were constructed between March and April, and were operational for 2 weeks prior to the first sample set. Five sample sets were taken insitu from household units during April and May 2014. A secondary UV filter was added in order to eliminate remaining coliform bacteria from the sand and acai filter to make the water potable. Case Study 5 was undertaken at the Federal University of Espiritu Santo, Vitoria, which is located in a region of Brazil with differing local sand composition [10]. This exercise utilised a sand and gravel filter with a larger volume and smaller grain sizes than those in Para State. Two identical filters were operated daily, typically filtering $8m^3/m^2$ per day, on the University campus over the course of 110 - 130 days. This filter performed well with a reported 80% reduction in turbidity and colour. Coliforms were not completely eliminated and UV light was used for post-filtration disinfection.

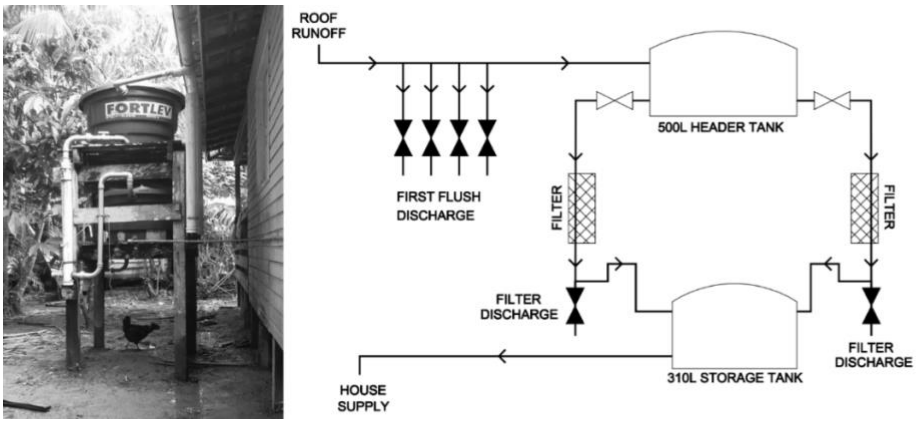



**Figure 4:** Rainwater Harvesting (RWH) system on Ilha Grande.

*2.7 Other water filter studies employing activated acai carbon*

Another study at the Federal University of Para [17], which did not directly relate to rainwater harvesting, utilised activated acai carbon for the filtration of heavy metals from river water. This study highlighted that these fruit by-products require heating to temperatures of around 400°C to be viable for filtration. Samples were taken at 19 different locations at 3 depths per location. This study found that the use of activated carbon reduced heavy metals from river water samples by 67.46% for aluminium, 41.67% for chromium and 65.15% in the case of zinc. Pereira [16] also highlighted the potential of activated acai carbon as secondary filtration for domestic tap water, in this case in the town of Moju, Para where the acai filter was found to reduce iron content to acceptable levels and eliminated detectable presence of e-coli.

## 3. Results and discussion

The key results associated with the removal of turbidity, colour, pH and coliforms for the five studies highlighted in Figure 5 are presented in Figure 7 in terms of their percentage reduction (i.e. from raw to filtered water samples). The associated publications either detailed a reduction in coliform numbers or describe whether e-coli presence was found on a yes or no basis. The inconsistencies in these previous bacteriological studies, has prevented the author from plotting a comparative graph/dataset. All of the aforementioned publications reported either the presence of e-coli or coliform in the filtered samples. Given that Brazil's Health Ministry requires the removal of e-coli and coliforms, all of these publications recommended either post-filter chlorination or UV treatment to remove bacteria prior to consumption.

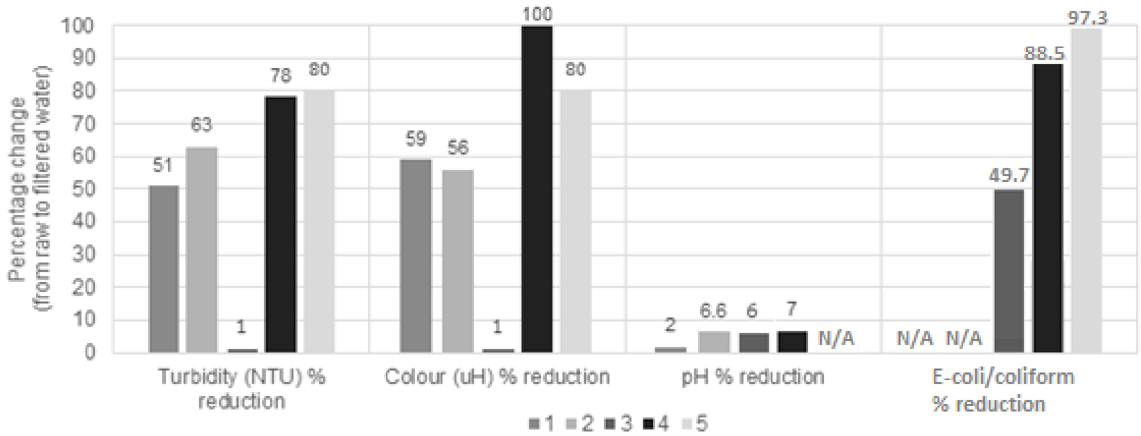



Figure 5: Average % reduction for RWH filter cases where comparable results available.

With the exception of Filter 3, all of the previous trials gave a high reduction in terms of dissolved solids, with Filters 4 and 5 performing exceptionally well in colour and turbidity reduction. A small reduction in pH occurred across the filters, this data was not available for Filter 5 but a similar change might be expected as the other sand and gravel filters. In terms of the reported testing routines, the length of time that the filters were in use for prior to samples being taken varied. Filters 1,2 and 5 were in use for ~90 days prior to the sample sets being taken, whereas 3 was new and 4 was insitu for 2 weeks prior to testing. Older filters would be expected to exhibit lower flow rates and worsening contaminant removal. The poor performance of Filter 3 might relate to filter materials passing through which had not properly been flushed before first use. All of the reported raw water samples failed to meet the Brazilian Ministry of Health standards for turbidity (i.e. of 1 NTU). This failure pattern, with the exception of Filter 4, is once again repeated for the Ministry's standards for colour. In terms of the filtered water samples, all filters with the exception of Filter 3, achieved the Ministry's standards for both turbidity and colour. Filter 3 gave satisfactory results for colour only within its first three months of use, however so did the raw water in this sample set. Filter 4 maintained the same physical size as Filter 3, however, 100mm of Acai carbon was added to the filter medium. It appears that this produced comparable percentage changes from the raw water case to Filter 5 with much less material volume, however, filter 5 was 75 days older at this point and would therefore not have been in optimum condition. Further testing as filter 4 ages could indicate that the powdered nature of the carbon particles enhance the filtration process in a small volume filter. Filters 2 and 3 [9] concurrent field trial yielded similar results, Filter 2 removed 12% more solids, but used double the volume of filter materials.

## 4. Conclusions

This paper has reviewed potable water issues experienced by a number of river island communities to assess whether Rainwater Harvesting techniques might be used to meet local water requirements where communities are not served by the mains water supply. Previous community surveys have indicated that nearly half of local residents may be consuming water from potentially contaminated sources.

On-going attempts to derive locally appropriate rainwater collection and treatment processes constructed and trialled water filters comprising of different mixes of sand, gravel and activated carbon derived from by-products of local fruit processing industries. The studies also highlighted the need for post-filtration disinfection. The length of time that each of these filters had been operated prior to the reported samples being taken varied. Older filters would be expected to exhibit lower flow rates and worsening contaminant removal. It appears that filter type 4 with sand, gravel and activated carbon was efficient at reducing colour and dissolved solids from the raw water state versus its physical volume, however this was a relatively new filter. To ascertain if filters with finer materials such as the powdered nature of the acai carbon or finer Espírito Santo sand improve performance, these filter types should be tested concurrently to measure performance. Using a layer of finer material could improve efficiency where coarser sands and gravels are only available locally. Further controlled testing is required to measure the effectiveness of the acai to a similar volume of medium with a finer sand. None of the rainwater harvesting filter tests examined nutrient or metals content.

In terms of sustainability, the carbonisation process utilises a considerable amount of energy, and it should be ascertained whether it is the carbon that optimises the filter, or if other available fine material in a smaller diameter filter would achieve the same effect by slowing the filtration process. It would be useful to compare cost and performance against a commercially produced filter in order to examine the overall sustainability of producing carbon from fruit processing waste for rainwater filtration, moreover where access to financial support is limited. Lack of resources and political barriers impact peripheral communities' access to services, therefore support from NGOs, in this case principally Caritas, local community and local university groups has been required to successfully execute pilot projects. Cuts to budgets for education and community organisations would have an effect in terms of scaling up these projects for greater impact.

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