STUDY OF THE RAINWATER CONSERVATION IN THREE TYPES OF RESERVATORIES: CONVENTIONAL, UNDERGROUND CONVENTIONAL AND UNDERGROUND WITH SAND

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1. INTRODUCTION

Brazil has 12% of the fresh water of the world, but it isn't well distributed inside of the country. Most of it is in the North, which has small part of the population compared with other regions of the country (TOMAZ, 2001).

To supply this demand, there are many alternative sources of water, such as wastewater reuse, technique that has been highly studied in San Diego, USA (HEFFERNAN,2015). Another technique is the rainwater harvesting, which depending on the purposed use is only necessary to make the removal of the thicker solids that are carried with the water, and also making a first flush diverter, which discard the first one or two millimeters of the rain (ABNT, 2007).

Even the rainwater having a good quality, is needed to be saved in a way to preserve it's quality, for it doesn't decrease while it is kept in the reservatory. According to a research held in Minas Gerais, Brazil, the rainwater quality was affected mainly because of the reservatories which the water was kept, independent if the reservatory was a new one or not (SILVA, 2006).

With the intention to a have a longer rainwater quality, AREED (*Association Reseau Expert Environnement Developpement*), a French Non-Governmental Organization, built in Madagascar Island an underground tank that saves the rainwater in the middle of the sand. With this technology the rainwater doesn't suffer with the weather and pathogenic vectors aren't able to evolve inside the tank, being proved by the users of the technology that the quality of the water last longer, but even being proved by the users, there aren't any scientific study proving it or not, taking this on concern, this study had this intention.

Were built three pilots: one of them representing a conventional water tank, in another words, it was just a plastic material recipient saving the rainwater, it was called RC (Conventional Reservatory). The second pilot represented the underground reservatory, and it was called RE (Underground Reservatory), it was built using two plastic recipients, one exterior to the other, and sand was put in the space between they, and the water was held inside the interior recipient; The last pilot was similar to the second one, being different because there was also sand in the interior recipient, where the water was held in, this pilot was called RA (Sand Reservatory). The rainwater used in the research was collected in the property of Raphael Autran, north part of the Florianópolis Island, Brazil, in the neighborhood of Ingleses do Rio Vermelho.

All the research was developed in the Water Potabilisation Laboratory (LAPOA) and Integrated Laboratory of the Environment (LIMA) in the department of Sanitary and Environmental Engineering in Federal University of Santa Catarina (UFSC), Brazil.

2. OBJECTIVES

2.1 GENERAL OBJECTIVE

Compare the water conservation in three types of reservatories: A common one; A common underground the soil and an underground reservatory filled up with sand.

2.2 SPECIFICS OBJECTIVES

Compare the physical-chemical and bacteriology characteristics of the rainwater that was held in three types of reservatories: a conventional, a conventional underground the soil and a underground reservatory filled up with sand.

Evaluate which one of the three reservatories is able to preserve the water quality.

3. REVIEW

3.1 RAINWATER HARVESTING HISTORY LINE

Rainwater Harvesting seems to be something new, but has been made since thousands of years ago (JAQUES,2005). In Thailand, according to Prempridi, Chatusthasry (1984), there are registers dating

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from 1500 b.C., when citizens from Thailand used to dig holes and used that dug sand to build walls around the hole, and inside it they saved the rainwater. According to the same authors there are registers of the evolution of the technology, when they used to associate the technology in religious temples, and nowadays, having more contact with other countries, they were able to build larger tanks utilizing linear fibers.

Nowadays, the rainwater harvesting technology has been used in many regions of the world. According to Jaques (2005), in California State, USA, financings are offered to the interested ones be able to install rainwater harvesting systems.

The same author tells about China's example that built water tanks to supply potable water for 15 million people.

In Brazil there are the P1MC program (one million cisterns project), that aims to guarantee the access to good quality water for the living families in the arid region in Northeast of Brazil. The program was able to help not just the families, but also the rural communities, raising the school attendance, decreasing the diseases there are transmitted through contaminated water and decreasing women housework (Articulação do Semiárido – ASA, 2015).

3.2 RAINWATER QUALITY

Usually the rain water quality is excellent for many purposes, including to drink, except in locals which have high atmosphere pollution, or being densely populated or industrialized. (NETO, 2004).

According to the same author, even in these areas, which provide depreciation of the rainwater quality, the chemical quality (for example values of pH), remains in a good quality for many uses, including to dilute salted waters. About microbiological contamination, it is even rarer than chemical contamination. But, according to Figueiredo (2001) *apud* Mantovani et al. (2012), rainwater usually are more acid, having pH values surrounding 5,6. But according to Fornaro (2006), values of pH around 5 in rain water have been found in non-polluted regions, depending on the efficiency of the "atmosphere cleaning" by the rainwater, and depends on geographic conditions of the sulfur and nitrogen cycles and the emissions of organic acids, so is important to emphasize that just pH values aren't able to evaluate the contamination level of rainwater.

According to Neto (2004) rainwater quality doesn't depends exclusively in atmospheric conditions, but it also depends in the catchment area, gutters, the connection between the catchment area and the reservatory, and at last the sanitary protection of the tank. The same author affirms that many studies which examined the rainwater quality of rainwater saved in reservatories concluded that these ones usually attend the World Health Organization standards, even disease cases related to the consumption of rainwater being known (SILVA, 2006).

According to the same author, there are many aspects that also influence in harvested rainwater quality, such as first flush devices, the way the water is taken out of the reservatory, how you disinfect the rainwater in the reservatory and the periodic cleaning of the reservatory. First flush devices has the intention to retain debris that could worse the quality of the harvested rainwater.

A research in Uganda from Ntale e Moses (2003) demonstrated how first flush devices help to preserve the quality of harvested rainwater. In their study they made analysis of the quality of the water inside the reservatory and inside the first flush device and the following results were obtained:

Figure 1 – Results of initial water, first flush device water and kept water in Uganda

Parameter	Initial Water	Water in First Flush Device	Harvested Rainwater
Turbidity (NTU)	5	42	3
Apparent Color (Pt Co)	26	125	9
Conductivity (µs/cm)	9	41,7	14,3
Thermotolerants Coliforms(Nº / 100mL)	26	4	0
Fecal Streptococcus (Nº / 100mL)	83	200	0

Source: Adapted from Ntale and Moses (2003).

With it, is able to observe how important is to use first flush devices to maintain the quality of the harvested rainwater.

A research made by Murakami and Moruzzi (2008) corroborate with the research made by Ntale and Moses (2003), they complemented that even with the first flush device installed, is necessary to discard the correct volume, otherwise there will be no difference with it or not. In the same study it was demonstrated that in a reservatory with non chlorated water, the quality of the harvested rainwater usually increases, but it can oscillate during the time, and these results weren't discussed in the same research.

Even having a good quality, is important to emphasize that depending on it final use, this water haven't the need to have a good quality. Just like Group Raindrops (2002) *apud* Kammers (2004) demonstrated:

Figure 2 – Rainwater uses and necessary treatments.

Water Use	Necessary Treatment
Gardening	No treatment
Fire prevention and air conditioniing	Only the ones to preserve the equipment
Fountains and lagoons, toilet flush, clothes and car washing	Hygienical treatment
Pool/Bath, drinking water and food preparation	Desinfection

Source: Group Raindrops (2002) *apud* Kammers (2004).

3.3 CONSERVATION OF THE RAIN WATER IN DIFFERENT WAYS

Just like the materials of the water tanks are not the same, what it is filled with can also change. Even the most of the types of the tanks having no filling, it is interesting to highlight two technologies that are being applied around the world.

3.3.1 UNDERGROUND DAM OR SUBMERGED DAM

Underground dam is that one formed by a wall or rock till a height higher than the alluvion, so in the raining period water is able to be hold there. The submerged dam has it wall completely under the ground, so the water is kept in the soil itself. (SANTOS, FRANGIPANI (1978); MONTEIRO (1984); SILVA, REGO NETO (1992) apud TEIXEIRA et al., (1999))

3.3.2 UNDERGROUND RESERVATORY FILLED WITH SAND

This technology is really new and it is similar to the underground dam. But, differently, it doesn't harvest the water which is already on the ground, but from a catchment area, and after that it is saved in a underground tank which can be made from a non-permeable material, and to use this water it is pumped out.

The *Association Reseau Expert Environment Development* (AREED) developed this type of technology in Madagascar Island and in Thailand, and it was completely effective for its purpose. This kind of system has many advantages, such as low initial investment, because it use only local materials; It is underground, so you can't see it and it doesn't suffer with the weather, and because of all of this advantages it has a long life cycle. (PSEAU,2015)

4. MATERIALS AND METHODS

To analyze the water conservation in the three types of reservatories: conventional, underground conventional and underground filled with sand, were built three pilots, each one of them representing one type of reservatory. The pilots were built and kept in Water Potabilisation Laboratory (LAPOA), and the analysis were also conducted in this laboratory and in Integrated Laboratory of the Environment (LIMA), both of them located in Sanitary and Environmental Engineering Department in Federal University of Santa Catarina State.

4.1 RAINWATER

The collected rainwater was from Florianópolis, Santa Catarina, Brazil. It was collected from a roof and afterwards kept in an reservatory, and the samples for this research were collected inside of the reservatory.

The catchment area was about 70m², and part of the roof was made of ceramic tiles and another part made of an organic fiber. When the water was collected, there wasn't a first flush device, neither a previous filtration, because these parts of the system were being installed.

The first results of the analyzed water were:

Figure 3 - Initial values of the sampled water

Parameter	Value
pH	4,65
Apparent Color (PtCo)	15
Turbidity (NTY)	2,45
Temperature (ºC)	26,8

Electrical Condutivity (µS/cm)	21,5
Total Organic Carbon (TOC) (mg / L)	1,7
Total Coliforms (NMP / 100mL)	87,6
Fecal Coliforms (NMP / 100mL)	0

Also, was able to see small insects inside of the water, which weren't identified.

4.2 SAND

The sand is the same used inside of the reservatory and outside of it, because there is no interest of the composition of the sand outside of the reservatory, but the sand was washed to guarantee it wouldn't lose small grains during the analysis period. For each kilogram of sand, were used 10 liters of water to wash it.

4.3 DESIGN AND PILOTS CONSTRUCTION

The three pilots were designed to store the same amount of water. In all of them were used trans lucid plastics of different sizes. After finishing the construction, they were covered with two layers of black tarpaulin, to don't let pass solar rays.

The water was collected from the pilots using the correct hydraulic connections, utilizing 20mm PVC pipes, flanges and taps. More details about the pilots are possible to see on the schemes below.

The pilot simulating the conventional reservatory was made with just one plastic box of 26,5 liters.

Figure 4 - RC reservatory side-view. Measures in centimeters

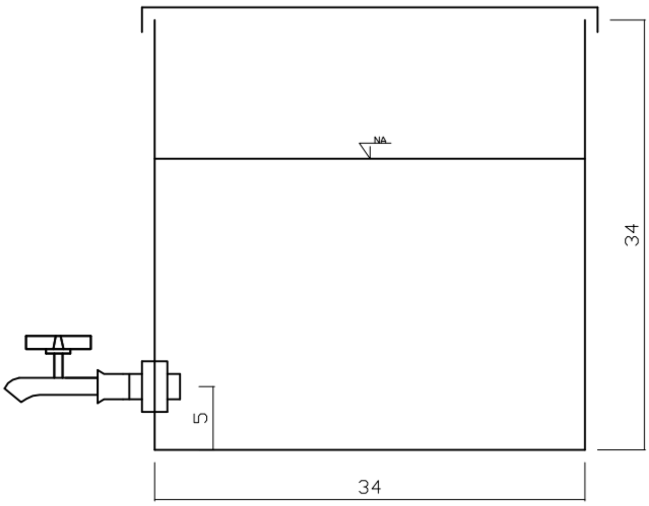

Figure 5 - RC reservatory front-view. Measure in centimeters

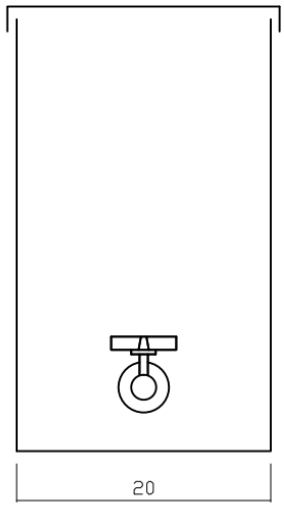

Figure 6 - Photo of RC reservatory

In the pilot simulating the underground reservatory was used one box of 26,5 liters inside of a box of 90 liters, and in the space between them sand was putted in. To connect the inner reservatory with the tap there was a pipe.

Figure 7 - RE pilot side-view. Measures in centimeters

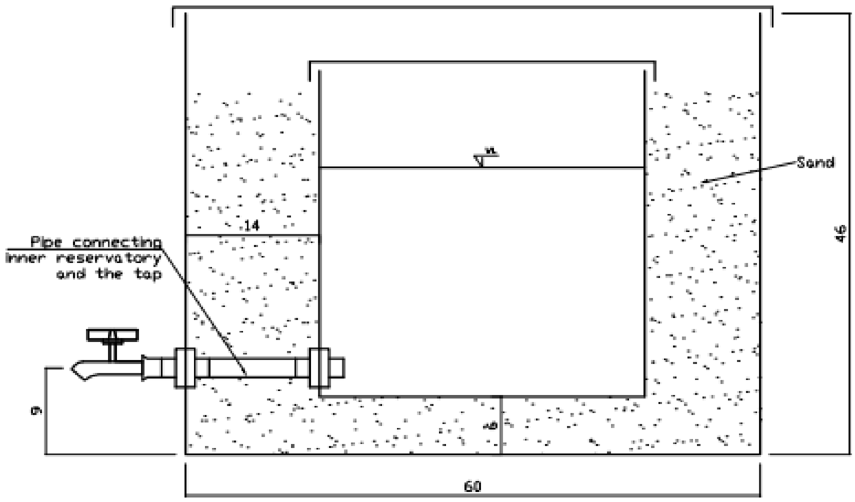

Figure 8 - RE pilot front-view. Measure in centimeters

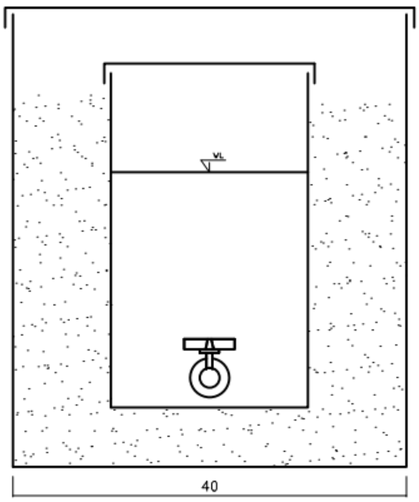

Figure 9 - Photo of RE reservatory

In the pilot simulating the underground reservatory filled with sand, were utilized a 56 liters plastic box filled with sand inner a box of 90 liters. With the same type of the sand, the space between the boxes was filled. Gravels and a mosquito net were put in the water outlet, inside the inner box, to prevent the loose of small grains from the sand.

Figure 10 - RA reservatory side-view. Measures in centimeters

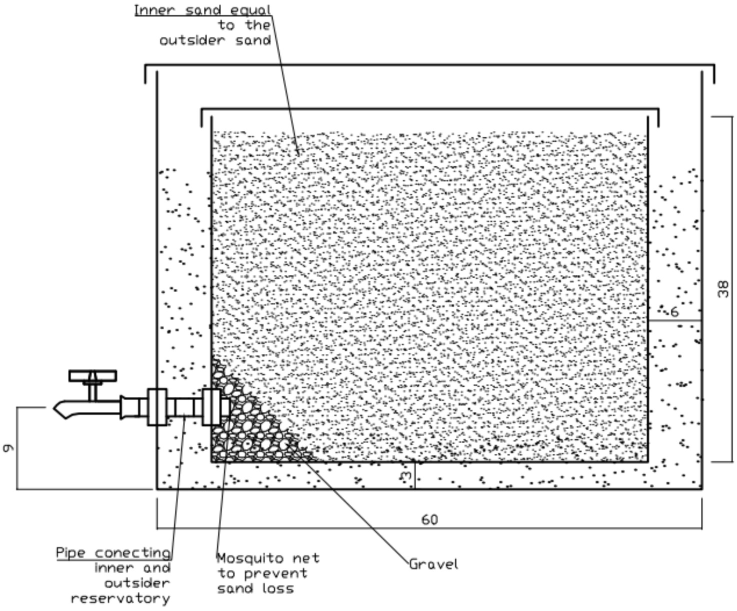

Figure 11 - RA reservatory front-view. Measures in centimeters

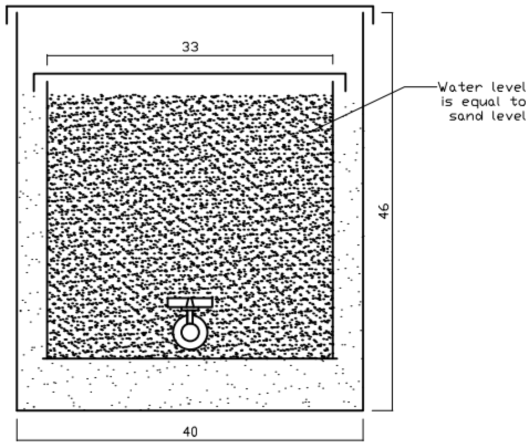

Figure 12 - Photo of RA reservatory

Figure 13 - Reservatories in place

4.4 PILOT MONITORING

Analysis were held in the days (day, month, year) 16/12/2015, 13/01/2016, 02/02/2016, 03/03/2016, 30/03/2016, 04/05/2016, 01/06/2016, and the reading of total and fecal coliforms were made after 24 hours in the hothouse. Before the water was collected in each analysis, 50mL were discarded from the RC and RA pilots, and 100mL in the RE pilot. These volumes represented the approximated volume of water which was held inside the pipes of the pilots.

4.5 REALIZED ANALYSIS

Each analysis, each method and equipment that were used are listed below:

Figure 14 - Parameters, methods and equipment used in the research

Parameter	Method	Equipment
pH		Multiparameter Meter HACH HQ40D pH sensor
Apparent Color	Spectrophotometric (2120C)	Spectrophotometer HACH DR2100
Turbidity	Nephelometric (2130B)	Nephelometer HACH 2100N
Temperature		Multiparameter Meter HACH HQ40D pH sensor
Electrical Condutivity		Multiparameter Meter HACH HQ40D Conductivity sensor
Dissolved Organic Carbon (DOC)		Shimadzu TOC- L TOC Analyser
Total Coliforms **Fecal Coliforms**	Enzyme Substrate Coliform Test (9223B)	COLILERT

5. RESULTS AND DISCUSSION

There were no fecal coliforms in any analysis that were held.

In relation with the temperature, there was a first decrease in March 3rd, that's why in the same place the pilots were, the air conditioner were turned on because of the need of another research to work. Beside of that, most of the results shows a higher temperature in the RE and RA pilots in relation with RC pilot. It probably happened because of the sand around RE and RA pilots, that probably worked like an insulating material.

The initial Conductivity of the water (21,5 µS/cm) is close to values presented by bibliography (Yaziz et al., 1989; Lee et al., 2010 e Mendez et al., 2010), for harvested rainwater collected directly without a catchment surface, it proved that in the research the catchment surface didn't affect in the conductivity. In the research of Mendez *et al.*(2010) samples of harvested rainwater from a green roof were analyzed, and the results of the analysis were higher, just like in the pilot RA of the presented research, proving that the material which the water was passing through influent in this value.

The decrease in the values of conductivity followed the decrease of the temperature. PH values evolved similar to the conductivity, especially between the fourth and fifth analysis, when the conductivity increased, the pH value decreased. But we can't establish a direct connection between them, because both of them are related with the presence of salts, and in the research salts weren't evaluated.

The Maximum Possible Number of total coliforms didn't follow any pattern of increasing or decreasing. RA and RC reservatories had pikes, but at the end established in values <1. Even MPN value of the RE had the value of <1 in one analysis, afterwards it increased again, and there wasn't no explanation for that. It also happened similarly in the research of Marakumi and Moruzzi (2008), that also worked with harvested and stored rainwater, and also wasn't found a reason for that, there was just the hypothesis of that being related to the life cycle and predation of the bacteria analyzed by the methodology of the research.

During the analysis period the turbidity was low in all of the results – except the first one of the RA pilot – they were below the value of the stipulated by Brazil Health Department (5 NTU). Low values were also found in the bibliography. In the research of May (2004) they found maximum values of 3,6 NTU and minimum values of 0,7 NTU. Jaques (2005) analyzed during a longer period and had higher results in the beginning which were decreasing during the analysis period, just like happened in the presented research with RA reservatory. The apparent color also had a similar behavior to turbidity.

Dissolved Organic Carbon values (DOC) initially increased, but during the analysis period they decreased, at the end there wasn't so much difference between the values in each reservatory. In RA reservatory, even with the water being held in all analysis period in the middle of the sand, there were values even smaller than the values of the other reservatories (RE and RC), but DOC of RA reservatory had a smaller DOC decreasement ratio comparatively with the other reservatories.

In the research of Lara *et al.* (2001) DOC values were smaller in wet periods, and that could be a reason of the samples presented in this research started with small values, because the samples were taken in December of 2015, which is a very wet period in Florianópolis, place where the samples were taken from.

Similar values were also presented by Mendez (2011) in the samples prevenient from concrete and metal tiles, and from cool roofs. Although, in green roofs, DOC values were so much higher than RA pilot, proving that to influence in DOC values, is necessary to have a more adequate place, just like the soil from the green roof, and not just the sand.

Also, at the end of the analysis period, there were small debris in RE and RC reservatories. RE reservatory had blacker debris and RC had browner debris. It's believed that these debris are mosquitoes's eggs that didn't hatch because they didn't had the right conditions for that.

Figure 15 - Results of the reservatories

	RE	RA	RC
	Maximum Value **Medium Value** Minimum Value		
Temperature (ºC)	26,8 **24,39** 21,4	26,8 **24,05** 21,5	26,8 **23,94** 21
pH	6,21 **5,42** 4,65	6,29 **5,60** 4,65	6,13 **5,56** 4,65
Conductivity (µS/cm)	78,7 **35,89** 20,6	136,1 **99,13** 21,5	46,6 **29,65** 20,7
Turbidity (NTU)	2,45 **0,59** 0,1	25,7 **3,83** 0,132	2,45 **0,59** 0,099
Apparent Collor (PtCo)	15 **6,13** 0	227 **33,38** 0	15 **7,00** 0
Dissolved Organic Carbon (mg/L)	13,75 **5,93** 1,6	9,942 **5,53** 1,002	13,16 **5,78** 1,7
Total Coliforms (MPV/100mL)	250,4 **164,80** 0	93,2 **21,91** 0	121,1 **17,30** 0

It's possible to perceive that there wasn't so much difference between any results of the three reservatories, instead of Total Coliforms results of RE reservatory, which there wasn't any explanation for that had happened.

So, it's possible to conclude that the technology applied in Madagascar, Thailand and Araranguá city are viable looking at the technical point of view of the water quality that is kept inside of the reservatory.

It's recommended to keep analyzing the same pilots, it's also interesting analyze Sodium, Magnesium and Potassium concentrations, because they are very common compounds of the soil.

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