USE OF REUSE WATER FOR PUBLIC SUPPLY

Alcindo Neckel[1] Emanuelle Goellner[2] Tauana Bertoldi[1] Grace Tibério Cardoso[1] and Juliano Lima da Silva[1]
[1]Postgraduate Program in Architecture and Urbanism (PPGARQ) of the Polytechnic School at Faculdade Meridional, IMED, Passo Fundo/RS, Brazil
alcindo.neckel@imed.edu.br
tauanabertoldi@hotmail.com
grace.cardoso@imed.edu.br
juliano_lima_silva@hotmail.com
[2]Postgraduate Program in Agriculture and Environment of the Universidade Federal of Rio Grande of Sul, UFRGS, Porto Alegre/RS, Brazil
e.goellner@yahoo.com.br

ABSTRACT

The general goal of the applied research in the city of Passo Fundo/RS (Brazil) is to propose an analysis of microbiological factors for applicability of reuse water, suggesting alternative distribution systems in a sustainable way. Methodologically, the research involved sample collection at two effluent treatment stations and analysis of microbiological standards through garden irrigation, followed by a questionnaire to companies in order to diagnose rainwater use, as well as local water and energy consumption. The results point to the feasibility of reuse water distribution in non-potable purposes, indicating microbiological factors favourable to human health and thus proposing the distribution to users.

KEYWORDS: *Effluent Treatment Facility, Rainwater, Water Reuse, Water Supply*

I. INTRODUCTION

The constant world population growth in relation to the research [1,2] has generated great concerns for public managers regarding different demands for a rational water use. "The consumption of potable water, for this projection of increasing users", will need to be rethought, encouraging the need to increase the demand for water for irrigation, industrial processes, and public supply [3,4].

In relation to the available water quantity to meet these growing world demands [3,5] "more than 70% of the earth's surface is made up of water. This includes more than 97.5% seawater in the oceans and seas, 1.979% in glaciers, 0.590% in groundwater, 0.030% in rivers and lakes, and 0.001% in the atmosphere." However, according to the same authors the percentage of freshwater that is easily accessible for human consumption is about 0.007%, being found in rivers, lakes and rain. Brazil concentrates 8% of the world's freshwater, 80% of which is distributed by the state of Amazonia (Amazon rainforest) and the remaining 20% supply 95% of the Brazilian population [5-7].

Considering these demand scenarios, water resources are becoming increasingly polluted due to the lack of treatment after human, agricultural and industrial use, which end up contaminating these sources [4, 8-14]. An improved water resources management should mitigate these issues, using water in a rational way and creating programs to raise awareness of water conservation importance, as about 33% of the world population live without basic sanitation and 21% do not have sewage treatment [2,12].

Some countries such as Israel, for example, already employ water reuse having about 70% of its water coming from this mean [15]. The increasing demand for water resources has made the planned water reuse an issue of great importance, and water reuse should be considered as part of a more comprehensive activity that is rational or efficient use, including wastewater control and the consumption reduction of water resources [16].

In the case of Brazil, reuse issues are dealt in Resolution No. 54 of November 28th, 2005, established by the National Water Resources Council (CNRH), which conceptually determines the differences between indirect reuse waters and direct planned or unplanned waters [17]. The implementation need of water reuse systems may occur spontaneously in nature, in the hydrological cycle, or through human actions, whether planned or not [4].

Unplanned reuse is already being implemented without the necessary precautions by many Brazilians, transforming rivers into waste deposits. On the other hand, the planned reuse technique consists in using water more than once, after undergoing treatment, and then destined for other purposes [5,18]. In the same way, brackish water, which is second class water but not as salty as the sea, and agricultural drainage water can serve as reuse water. It is very important to emphasize that, for the effective reuse application, technical measures are necessary, such as: treatment systems evaluation, use criteria definition, adequate planning and monitoring, quality resulting from water and control of environmental impacts and benefits [4,18].

The reuse technique consists of alternatives of extreme necessity to avoid waste [12]. Reuse can be applied, mainly from sanitary sewers, and some companies are already applying water reuse for multiple uses, such as machinery and sidewalk washing and plant irrigation [12,14, 15-19].

Attempting to make the reuse technique more feasible, this manuscript aims specifically to demonstrate that reuse water can be stored and distributed by implementing a supply system, contemplating residential buildings, schools, industries, businesses, among other services, both public and private in the city of Passo Fundo-RS, Brazil, in order to reduce potable water consumption in garden irrigation, toilet use and car and sidewalk washing. Therefore, aiming to reduce potable water and electricity monthly costs

The advantages of thinking about a reuse system in Wastewater Treatment Plants (WTPs) is that water after treatment processes can be used for landscape irrigation, agriculture, industrial uses, aquifers recharge, civil construction use and other environmental purposes as the application in swamps, among others [12, 20-14]. The selection of the reuse system will heavily depend on the system users' perception, regarding water use rationality [21, 22]. This treated water will need to meet quality standards established in each country, so that the physical-chemical and microbiological characteristics of treated wastewater are acceptable to human health [18, 23-24].

The processes involved in the treatment should be monitored periodically, so that public health efficiently benefits from water reuse. They emphasize the need to improve efficiency in wastewater treatment and reduce the reuse system contamination risk for the population [24].

The present research focused its studies in the city of Passo Fundo (South Brazil) due to its hydrographic richness with various springs that origin five of the twenty-five hydrographic basins found in the State of Rio Grande do Sul, such as: Passo Fundo River Basin, Alto Jacuí Basin, Apuaê-Inhandava Basin, Taquarí-Antas Basin and Várzea River Basin [4,18,24, 25-26].

In this way, the manuscript counts on the following organization: Introduction; Materials and Methods; Results and Discussion (Microbiological survival analysis under storage conditions, Bacterial survival analysis after water reuse for garden irrigation, Comparison of physicochemical parameters with recommended limits and Proposed water distribution system for the city of Passo Fundo); Conclusions (Recommendations for future research); Acknowledgements; References; and Authors.

II. MATERIALS AND METHODS

The research was conducted in the city of Passo Fundo (geographical coordinates 28º07' to 28º25' South and 52º17' to 52º41' West and currently covers a territorial area of 754.40 km²), located in to the North of the Brazilian state of Rio Grande do Sul [27]. It is a city of ample water demand, contemplating four water springs responsible for the supply of 302 municipalities and for supplying water for 61% of the state of Rio Grande do Sul, covering about 6.8 Million citizens [27]. Therefore, the applicability of reuse techniques allows water treatment and distribution of already treated water for non-drinking purposes with the aim of reducing costs, since users will not use potable water for other uses, allowing water resources preservation and greater protection of underground aquifers present in this region.

Initially, the study was conducted in two Wastewater Treatment Plants (WTPs), where the research was developed in three stages. The first stage consisted in the water microbiologic study to evaluate if such water could be stored after the anaerobic treatment. In the second stage, field surveys were made in order to know which companies employ reuse of treated water in their businesses. The third stage contemplated the economic feasibility estimation so that reuse water could be used again through a distribution network.

Stage 1 included tests with the purpose of observing the behavior of water pathogenic load, aiming to obtain data on bacteria survival under wastewater storage conditions and the feasibility of use in gardens. For this purpose, two wastewater samples were obtained from the treatment plants for the conservation test, which were stored in 50 liters plastic containers. These samples were collected for fecal and total coliforms analysis in the Laboratory of Microbiology of the Faculty of Food Engineering, University of Passo Fundo (UPF). Analyzes were done at 1, 2, 7, 10, 14, 17, 21, 24 and 30 days after initial collection.

In order to assess how the collected wastewater reacted after being introduced into the environment at the end of the water treatment, a 10x30m yard was delimited, from which small soil samples were extracted at different locations. Thus, treated water from the UPF treatment station was applied with a suction effluent collector, with a total capacity of 200 liters. Before this application, bacteria levels were measured using two 100mL samples. After water application, grass samples were collected at five points in the study area and placed in plastic bags. This procedure was repeated on days 1, 2, 3, 4, 7 and 10 after application of the treated water.

From the garden samples collected, bacteria were isolated by washing the collected material in the same sample bag with 1 liter of sterile double-distilled water. Contents were filtered and then placed in 100 mL flasks for analysis of fecal coliforms, totalizing two flasks per sample.

Microbiological analysis: After being isolated for 48 hours in a bacteriological oven at a temperature of ± 1°C, the presumptive test of the samples was carried out. A repetition of the presumptive test was performed to confirm the presence or absence of fecal coliforms. For the confirmation of the presumptive test the samples remained for 48 hours in a water bath with stirring at a mean temperature of 0.2°C. With this procedure, it was possible to determine the presence or absence of the coliform group, as established by the standard methods [28]. With the analysis data, behavioral curves of the bacterial population were obtained, both in storage conditions as well as in soil application tests of the studied reuse water.

The second part of the research included questionnaires application along Brasil Avenue, using the Stated Preference Method (SPD). Among the three groups classified [29] regarding data obtained from PD experiments (rating scale, preference order or ranking, and choice of the most attractive), it was chosen the method of ordering the alternatives, in which options are simultaneously presented to the interviewees with the objective of placing them in order of preference.

Based on the water reuse idea, this survey aims specifically to know which industries reuse rainwater in routine activities (garden irrigation, toilet use and washing cars and sidewalks) and if this practice results in electricity and potable water savings. For the questionnaire application, it was identified which possible typologies use greater volumes of monthly treated water in relation to their facilities and activities, being defined as: residential and commercial buildings, schools, industries, car dealers and agricultural machinery, among others. Twelve companies collaborated in answering the questionnaire. Therefore, costs and materials to develop a reuse system were identified and calculated to suggest a system to these companies, so that this water could reach companies.

III. RESULTS AND DISCUSSION

MICROBIOLOGICAL SURVIVAL ANALYSIS UNDER STORAGE CONDITIONS

Fecal coliform bacteria survival test experiments under storage conditions were conducted in order to determine if there may be changes in bacterial population, in the case of having to store the effluent for later reuse, which may influence human risk probability of exposure to these pathogens.

As can be observed for the case of UASB reactor effluent, the initial bacteria population was initially large both for total coliforms and fecal group, with an average MPN of 35,000/100ml. Two days after effluent collection and storage, the population of the fecal group fell to 9.4% of the initial population, while the total coliform group remained unchanged. In storage day 7, coliform group population represented 27% of the initial population, while the fecal coliform group presented a population that corresponds to 8% of that verified in the effluent collection before storage. After 10 days, these populations corresponded, respectively, 18.2% and 5.1% of total and fecal coliform groups. In day 17, population continued to decline and total and fecal coliforms represented only 0.54% of the population initially observed in the effluent before storage. The population remained low until 24 days, in spite of the fact that the total coliform group experienced a small increase in the MPN value in day 21.

In Araucária WTP wastewater, initial bacterial population was much lower, due to the fact that it is a system of serial stabilization ponds, with a greater reduction efficiency of pathogenic microorganisms than the anaerobic reactors [19, 24-18]. The bacteria population remained low in the first days until day 7 when it experienced a significant increase for both groups, being higher for the fecal coliform group, which had a highly significant increase in the population (MPN of 180/100ml to 54,000/100ml). After a small decay in the population until day 10, there was again an increase in the population of the two groups analyzed, with the total coliform always showing a higher growth throughout the study period than the fecal coliform group. This growth peaked at 21 days and then showed a significant drop at 24 days, when populations of the total and fecal coliform groups represented only 7.7% and 7.1%, respectively, of the populations observed on the previous date of collection and evaluation. However, it should be highlighted that the remaining population in both groups is highly elevated, far superior of any reuse quality standard [18].

As for the bacterial different behavior in the two systems, perhaps the fact that better explains is the characteristic of bacterial population growth process in a controlled and limited environment. In the case of WTP-UPF, with an up flow anaerobic reactor system, the initial bacterial population was very high, due to the process low efficiency for this parameter, and during its entire storage period, its fall can be explained by nutrient availability reduction and/or probable depletion of other essential factors to bacterial growth. In the WTP-Araucária case, low initial bacterial population still had the essential factors for its growth and in those storage conditions experienced an accelerated growth that is typical for bacteria, and after 21 days reached its maximum value, and then, probably, by the same factors alleged for the previous case, experienced a significant drop in its population.

However, for the WTP-Araucária effluent, observed data points to the possibility of maintenance and/or elevation of the bacterial population of these two groups, leading to a significant associated risk, since the comparison between the systems results points to opposite directions.

Effluents physical-chemical analysis results show variations for Biochemical Oxygen Demand (BOD) for WTP-UPF of 7-165 mg O2/L and of nitrogen of 9.5-56 mg/L, while for WTP-Araucária BOD ranged from 8-64 mg O2/L, total phosphorus from 0.6-8.2 mg/L and total nitrogen from 0.8-12 mg/L. It is known that bacteria are the group of microorganisms with the highest presence in wastewaters and that their population growth is limited mainly by the availability of nutrients such as organic matter that constitutes their main source of carbon and energy (Nitrogen and Phosphorus). Preliminary analysis of the cited data showed that in the stored effluent from both systems, these sources were available in relatively high values. At WTP-UPF, however, this availability may not have been compatible with the higher population needs and hence rapid decline was observed. On the other hand, in the case of WTP-Araucária, lower initial population may have found sufficient organic carbon load, besides nitrogen and phosphorus, due to the process greater efficiency, capable of temporarily sustaining a peak of population growth, in which after a certain period collapsed, due to a probable exhaustion of these nutrients [30].

BACTERIAL SURVIVAL ANALYSIS AFTER WATER REUSE FOR GARDEN IRRIGATION

In these experiments, the main objective was to determine bacteria survival rate of the coliform group after effluent reuse from WTP-UPF in garden irrigation, in order to evaluate the potential risks associated with the contact of people with the vegetation. For that, a test was carried out in which a single application was made and another, with several applications, simulating a garden irrigation common condition in the summertime and with rainfall deficiency.

Initial bacteria population presented relatively high values, both in terms of total coliform group and fecal coliform group. One day after the application, through the analysis of the collected material washed water, it was observed a clear fall in MPN values, and in the total coliform group, data pointed to a population representing 10.38% of the values observed in the effluent before irrigation. For the fecal coliforms group, this population represented only 0.83% and remained unchanged until 10 days after garden irrigation. In two days, the total coliform group represented 5.89% of the initial population, remaining practically unchanged for 7 days, with a fall that represented 3.58% of the initial population.

However, in contrast to the fecal coliform group, total coliform group presented higher MPN values when compared to recommended standards in the literature (that vary from 200-1000/100ml), with a normal range for water reuse of 1000/100mL. These values may risk human health [18,31].

Results of show that although the microbial population for the analysed groups was extremely high (mean of the population observed in the three applications), there was a significant reduction in this population on the first day after the effluent application, respectively 1.16% and 1.4% for the total coliform and fecal coliform groups. Values were well above the recommended quality standards for this type of water reuse. On day 7, while an increase in the total coliform group population was observed, fecal coliform group population represented 0.10% of the initial population, falling to 0.052% after 10 days and remaining as such until the end of the trial period. In the total coliform group, the behaviour was similar, despite an increase in the population in day 17, but the MPN value was within the recommended limits.

According to the microbiological guidelines recommended by the World Health Organization [32], reuse irrigation condition for parks, sports fields and cultures to be ingested raw is 1000/100mL. Data from trials show that although there is a high decrease in bacterial survival, the remaining bacterial population may present microbiological risk, as observed in the total coliform group in the single application test, which remained above the recommended limit until day 10. Thus, it requires greater efficiency and control in the treatment systems as well as in monitoring after irrigation.

The anaerobic reactor system used in the WTP-UPF presented low efficiency of bacteria population reduction, which determined the presence of high populations in the reuse effluent, also demonstrating that besides the system used, design influence and operational aspects on the final quality of the reuse water, requiring greater quality control. However, it demonstrates effluent storage feasibility and possibly it can be used, among other purposes, for garden irrigation. According to the research [33, 14], reuse water can be used for irrigation purposes, after treatment, and it is highlighted [34] that irrigation can become an alternative technology for garden maintenance, or even in the cultivation of vegetables without contaminating plants.

Argue that water reuse "for irrigation is a valuable strategy for the preservation of available water resources" [21, 14]. On the other hand, costs for implementing a reuse water distribution system can be very high. This is due to constant maintenance to avoid undesirable water leaks, which could jeopardize the system [35, 36].

COMPARISON OF PHYSICOCHEMICAL PARAMETERS WITH RECOMMENDED LIMITS

Sample analysis of physicochemical parameters of the two treatment plants were compared with recommended limits [31, 18]. Samples that presented values above these limits were accounted for. Data are presented in Table 1. The physicochemical parameters considered were pH, total phosphorus, BOD, oils and greases, suspended solids, ammoniacal nitrogen and fecal coliforms.

Table 1. Comparison of Treatment Systems Samples Parameters with the Recommended Limits for Reuse.

Parameter	**Recommended Limits [18, 31]**	**% of samples above limits**	
		UPF ETP	**Araucárias ETP**
pH	6.5-8.4	0	0
Total Phosphorus (mg/L)	2.0	NA	81.5
BOD (mg/L O_2)	3.0	92.5	58.8
Oil and grease (mg/L)	8.0	25.9	NA
Suspended solids (mg/L)	50.0	74.0	54.5
N-amoniacal (mg/L)	5.0	100.00	70.0
Fecal coliforms (NMP/100ml)	200.00 -1,000.00	60.2	46.7

Table 1 results show that the nonconformity index in relation to the limits used for both systems and for the considered parameters is high. In WTP-UPF case, the samples percentage with a value above recommended limit for treated sewage reuse was 92.5% for BOD, 74% for suspended solids, 100% for ammoniacal nitrogen and 25.9% for oils and greases. Similar results were observed in WTP-Araucaria, which had high percentages of values above recommended limits. The latter also presented samples with values above the indicated limit, 81.5% samples in total phosphorous and 70% of ammoniacal nitrogen higher than recommended. The results found in the fecal coliform group should also be highlighted, due to the associated microbiological risk.

These results demonstrate that treated sewage water reuse, depending on the system used and its operational efficiency, may require pre-treatment stages aiming to comply with recommended quality limits, environmental and public health safety. The use of treated effluents with techniques of reduced capacity of removing pathogens such as UASB reactors can impose limitations in water reuse in irrigation practices where there may be high exposure of people, such as irrigation in gardens and parks. Water reuse in such systems should consider sewage treatment techniques that reach quality parameters of the reuse effluent, considering aspects of environmental quality, public and agronomic health, as well as the compatibility of these requirements with irrigation techniques, soil characteristics and climatological conditions.

Second research stage consists on the field survey where companies were questioned in order to know which of them perform water reuse and rainwater use in its routine activities. Therefore, twelve companies were interviewed, and only four of them adopt procedures aimed at mitigating environmental problems with rainwater reuse (Table 2). These four companies use rainwater reuse systems, storing water in cisterns for purposes such as car and sidewalk washing, and toilets.

It should be highlighted that all interviewed companies use water treatment systems before returning it to the environment. For example, one of these systems includes three separator tanks in order to remove oil, grease, clay and detergent from water by decanting and filtration processes. Other companies return the water into the sewage network after leaving it in a pit about six meters deep that has its bottom coated with an activated carbon layer, which removes impurities from the water, letting it infiltrate naturally in the soil.

It can be observed that those four companies that implement water reuse have their own artesian wells, and there is no connection with water utilities in relation to their water consumption. Their associations with water utilities are made through fees, which range around R$ 100.00 monthly.

In contrast, eight of twelve companies do not have any water reuse process, and release water without treatment in the receiving water body. Just one of these companies has an artesian well. The other seven companies pay an average of R$ 395.50 per month to the water utility company, although the values greatly vary between R$ 47.00 and R$ 1,300.00.

In the Table 2, there is also the company named “Quatro”, which offers car maintenance services, containing in its establishment repair garage and car washing. Although it employs water reuse processes, it needs to consume electricity for its operation, thus depending on rainwater harvesting which is stored in cisterns, in order to reduce its monthly costs. These amounts range monthly from R$ 140.00 to R$ 12,875.00, obtaining an average of R$ 3,525.04 per month.

Table 2. Monthly energy and water costs of the twelve companies surveyed, and whether rainwater harvesting is performed or not.

Interviewed companies	**Electric power consumption (R$)**	**Water consumption (R$)**	**Rainwater utilization**
Company 1	1,000.00	1,300.00	No
Company 2	3,500.00	180.00	Yes
Company 3	2,000.00	-	No
Company 4	12,875.00	100.00	Yes
Company 5	900.00	250.00	No
Company 6	8,000.00	-	Yes
Company 7	3,000.00	200.00	No
Company 8	3,000.00	-	Yes
Company 9	6,000.00	-	No
Company 10	782.00	47.00	No
Company 11	140.00	-	Yes
Company 12	10,000.00	180.00	No

There are still few companies that have processes to reuse rainwater [2]. Therefore, when forecasting water reuse applicability in order to enable a more sustainable future for water treatment plants of Passo Fundo, it is proposed the creation of a substation for storage and distribution of these released waters after the treatment done by the WTPs, which is described in the next chapter.

PROPOSED WATER DISTRIBUTION SYSTEM FOR THE CITY OF PASSO FUNDO

After the two stages of the research, and having information of the microbiological properties of reused water that meet the standards for specific uses in counterpart with the number of companies that use rainwater for certain activities, a system of treated water distribution is proposed.

The reuse water system will embrace both wastewater treatment plants (WTPs) mentioned in this study. The construction of a central substation to receive reuse waters of the two WTPs would need to be located in the area covered by Embrapa Trigo (public company) located on the border of highway BR-285, because it is a centralized region and 659m high. Therefore, as the Araucária WTP is 636m high, the relation with the former site corresponds to 23 meters of planialtimetric slope, with 1,273km distance from the water catchment point. On the other hand, UPF WTP is only 71m high, which corresponds to 588m lower altitude of the point located in Embrapa Trigo, and at a distance of 2,0033km.

The water network will have four water tanks: the first one will receive water coming from the two WTPs; and the other three will serve as standby tanks, where water can remain stored for up to 25 days, reuse water can be stored and redistributed, because the longer it is stored, the smaller the amount of microorganisms present in the reuse water [8].

From this proposal, it is possible to suggest a system with conduits along Brasil Avenue, with secondary branches supplying buildings. For this, it would be necessary to install in each company that connects to the system a water consumption meter, valve and hydrometer. One of the advantages of this system is that it does not need reservoirs (water tanks), thus using direct network connection (Figure 1).

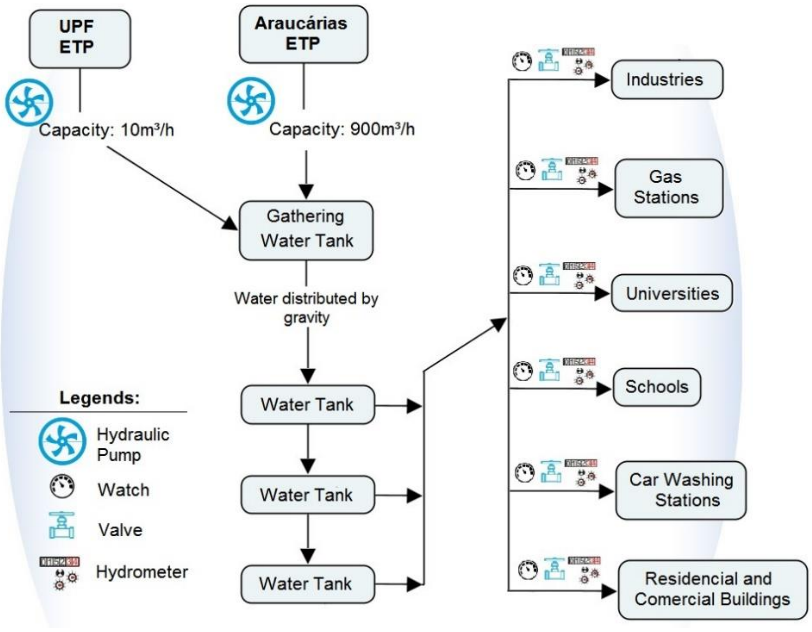

Figure 5. Distribution network scheme and respective receivers.

In addition, water will move from the receiving station to users by gravity, which will help reduce energy costs for companies as it will not need to use pumping from their artesian wells. In agreement with the ideas [2, 16, 33-37], that highlight that when low cost of effluent treating is combined with sensible water resources use through new technologies applications, it makes the environment increasingly more sustainable, making possible for future generations access to clean hydrological resources.

IV. CONCLUSIONS

According to the objectives proposed in this study, the results show that effluents reuse from domestic sewage treatment systems for garden irrigation purposes after treatment has remained favorable in relation to human health.

Bacteria survival of total and fecal coliform groups presented a distinct behavior in the conservation experiments and it is related to the initial population. In the anaerobic reactor system of WTP-UPF, with a higher initial bacterial population, there was a sharp drop in bacterial growth over the days, while in the stabilization pond system of WTP Araucária, with a very low initial bacterial population; there was a significate growth in population up to 21 days of storage, until they started to decrease.

Regarding the reuse water distribution system, it seems that its applicability will provide savings through the non-use of potable water for garden irrigation and washing car and sidewalks, and other non-potable purposes. There will also be financial savings in potable water and energy bills, due to the decrease in pumping practice used to draw water from artesian wells.

RECOMMENDATIONS FOR FUTURE RESEARCH

For future research it is suggested a detailed construction workflow and economic viability of the treatment system. Subsequently, environmental valuation studies would be necessary in order to pass along costs to the population.

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AUTHORS

Neckel, Alcindo. Graduation in Geography (UPF-2007). Master in Engineering, with the area of concentration in Infrastructure and Environment by the University of Passo Fundo (UPF-2010); PhD in Geography, Federal University of Rio Grande of Sul (UFRGS-2014). Post-doctorate in Architecture and Landscape Design from Cornell University (2017).

Goellner, Emanuelle. Graduation in Biology (UPF-2007). Master in Engineering, with the area of Concentration in Infrastructure and Environment (2010). He works in the area of Water Resources Management, Solid Waste Management, Environmental Sanitation and Corporate Environmental Management. PhD student in Agricultural and Environmental Microbiology at the Federal University of Rio Grande of Sul.

Bertoldi, Tauana. Graduation in progress in Architecture and Urbanism (IMED). Scholarship of Scientific Initiation of CNPQ. Center for Studies and Research in Urban Mobility (NEPMOUR). The lines of research: Governance in Sustainable Cities and Urban Mobility.

Cardoso, Grace Tibério. Graduation in Architecture and Urbanism from the University of São Paulo (USP-2007); Master in Materials Science and Engineering by the Department of Materials Engineering, School of Engineering of São Carlos (EESC-USP-2010); Doctorate in Environmental Engineering Sciences, Department of Environmental Engineering, School of Engineering of São Carlos (EESC-USP-2015); and postdoctoral degree in Sustainability by the Postgraduate Program in Sustainability, School of Arts, Sciences and Humanities (EACH-USP-2016).

Silva, Juliano Lima da. Graduated in Civil Engineer from the University of Passo Fundo (2014). Master in Architecture and Urban Planning (IMED). He has experience in Civil Engineering and Architecture, mainly working on the following topics: Building Information Modeling, project management, programming, Performance Standard, parametric design, structural engineering, wood structures.