Corn starch-based treatment improves rainwater quality
Liane Yuri Kondo Nakada and Rodrigo Braga Moruzzi

ABSTRACT

Rainwater harvesting can provide an alternative water source, which may demand little treatment, depending on the end use. Some starches have been used in water treatment as coagulant/flocculant/filtration aid, and might be applied as primary coagulant. Here, we show direct filtration with hydraulic rapid mixing, using 2–6 mg L⁻¹ cationic corn starch as primary coagulant, considerably improves roof-harvested rainwater quality, achieving removal efficiencies of up to 71.7% of apparent colour, 78% of turbidity, 1.1 log-unit of total coliform, and 1.6 log-unit of *Escherichia coli*, meeting guidelines for turbidity, even for potable purposes. Cationic corn starch has proved to be a suitable primary coagulant when filtration is performed in a single-layer sand filter (coefficient of uniformity: 1.8, effective particle size: 0.52 mm), at hydraulic loading rate of 450 m day⁻¹. However, a disinfection unit is required to meet an absence of faecal coliform.

Key words | corn starch, direct filtration, full-scale rainwater treatment, rainwater harvesting

INTRODUCTION

Population growth, water resources pollution, and water scarcity in specific regions have caused an increasing interest in rainwater harvesting. According to the United Nations Environment Programme (UNEP) (2002), less than 1,000 m³ per capita/year is catastrophically low water availability. In southeastern Brazil, Piracicaba River Basin (Campinas metropolitan area) and Alto Tietê River Basin (São Paulo metropolitan area) have, respectively, 408 m³ and 201 m³ per capita/year, and are facing water shortage.

Governmental agencies of many countries have been introducing policies to promote rainwater usage; nevertheless, little attention had been paid to the quality of collected rainwater until recently, when researchers across the world started trying to assess the quality of roof-runoff (Meera & Ahammed 2006).

Rainwater harvesting can provide a range of environmental and structural benefits, once it can reduce: (i) demands for mains water, relieving pressure on sources water, and leaving benefits to ecosystems; (ii) stormwater runoff and pollution; (iii) erosion in urban areas; and (iv) pressure on drainage systems in periods of high flow. Mainly, rainwater harvesting offers an alternative water source which demands little treatment for irrigation and non-potable uses (United States Environmental Protection Agency (USEPA) 2008; United Kingdom Environment Agency 2010).

Several studies have highlighted roof-harvested rainwater usually contains physical, chemical, and microbiological contaminants, which are washed from the atmosphere by the called wet deposition and from the catchment surfaces, where the dry deposition takes place in days without rain (Meera & Ahammed 2006; Lye 2009; Abbasi & Abbasi 2011; Ahmed et al. 2011; Mendez et al. 2011; Kwaadsteiniet et al. 2013). Contamination can also occur in any point of the harvesting system, such as gutters, pipes and tanks (Lee et al. 2010; Morrow et al. 2010). Thus, stored rainwater treatment is required prior to use. According to United States Environmental Protection Agency (USEPA) (2013), the complexity of the treatment system depends on the intended uses of the harvested rainwater, as well as the rainwater quality requirements in the particular location of the rainwater harvesting system.
The scientific literature reveals a lack of clarity concerning water quality guidelines and health-related standards for rooftop runoff. Worldwide, current standards and guidelines regarding microbial contamination of rainwater are shown to vary widely (Lye 2009).

In Brazil, the Norm NBR15527 – ‘Rainwater – Roof harvesting in urban areas for non-potable purposes – Requirements’ (Associação Brasileira de Normas Técnicas (Brazilian National Standards Organization) 2007) gives limit values of quality parameters for rainwater to be used for non-potable purposes, as toilet flushing, garden watering, vehicle washing, external cleaning, and industrial end uses.

In the United Kingdom, there are currently no regulatory water quality standards for rainwater use, although the UK Environment Agency presents some water quality guidelines (United Kingdom Environment Agency 2010).

In the United States, currently, there are no federal regulations on rainwater harvesting for non-potable uses (United States Environmental Protection Agency (USEPA) 2010). The state of Texas has published guidelines recommending minimum water quality for use of rainwater (Texas Water Development Board 2006).

In Table 1, we present a compilation of water quality guidelines for non-potable uses of rainwater, excepted where specified as ‘potable uses’.

Direct filtration has been reported as a suitable water treatment process for removing turbidity and faecal coliforms from water and wastewater (Babu & Chaudhuri 2005; Li et al. 2012).

Polyelectrolytes are long-chain organic molecules with chemical groups attached along the length of the chain, which become charged when the molecule is dissolved in water. Natural organic polyelectrolytes such as some starch products have long been used as coagulation/flocculation/filtration aids in water treatment. In special cases, polyelectrolytes may be used as primary coagulant (Environmental Protection Agency (EPA) 2002).

Recent researches have reported the successful use of starches for removing turbidity from raw water (Chatterjee et al. 2014; Hameed 2014) and wastewater (Fatehah et al. 2013). Ratnayake & Jackson (2006) studied the gelatinisation and solubility of corn starch during heating in water, as starches are insoluble in cold water. According to these authors, when corn starch is heated in water, amorphous regions within granules absorb water, resulting in destabilisation of their crystalline structure, phenomenon called gelatinisation, which is irreversible when temperature reaches 80 °C.

Considering the benefits of utilising rainwater with appropriate quality to the intended uses, as well as the potential use of starches and direct filtration in water treatment, the present study was carried out aiming to investigate a treatment for harvested rainwater.

Table 1 | Parameters of rainwater quality for non-potable uses, excepted where specified as ‘potable uses’

<table>
<thead>
<tr>
<th>Parameter of water quality</th>
<th>NBR 15527 (Associação Brasileira de Normas Técnicas (Brazilian National Standards Organization) 2007), Brazil</th>
<th>UK Environment Agency</th>
<th>Rainwater harvesting guidelines for Texas, USA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apparent colour</td>
<td>&lt;15.0 Pt-Co</td>
<td>Not objectionable for all uses</td>
<td>Not objectionable</td>
</tr>
<tr>
<td>Turbidity</td>
<td>&lt;2.0 NTU, &lt;5.0 NTU for less restrictive uses</td>
<td>&lt;10 NTU for all uses</td>
<td>Not objectionable, &lt;1.0 NTU for potable uses</td>
</tr>
<tr>
<td>Total coliforms</td>
<td>Absence in 100 mL</td>
<td>10 number/100 mL for external cleansing, 1,000 number/100 mL for garden watering and toilet flushing</td>
<td>&lt;500 cfu/100 mL, Absence for potable uses</td>
</tr>
<tr>
<td>Faecal coliforms</td>
<td>Absence in 100 mL</td>
<td>E. coli: 1 number/100 mL for external cleansing, E. coli: 250 number/100 mL for garden watering and toilet flushing</td>
<td>&lt;100 cfu/100 mL</td>
</tr>
<tr>
<td>Free chlorine residual</td>
<td>0.5–3.0 mg·L⁻¹</td>
<td>&lt;0.5 mg·L⁻¹ for garden watering, &lt;2.0 mg·L⁻¹ for all other uses</td>
<td>0.2 mg·L⁻¹, ≥0.2 mg·L⁻¹ for potable uses</td>
</tr>
<tr>
<td>pH</td>
<td>6.0–8.0</td>
<td>5.0–9.0 for all uses</td>
<td>Not objectionable</td>
</tr>
</tbody>
</table>

cfu, colony forming units; NTU, nephelometric turbidity units.
METHODS

Description of the site

Rio Claro is located in southeastern Brazil, in the northeast of the state of São Paulo, about 170 km from the capital city São Paulo. The municipality has more than 1,900,000 inhabitants, with an urbanisation rate of 97.5% (SEADE 2014).

The Meteorological Station (CEAPLA), located at São Paulo State University (UNESP), Rio Claro-SP, has provided historical information about rain events, making available the following data: annual average rainfall is 1,483.4 ± 200.6 mm; the rainy period is from October to March, when the rainfall average is 1,204.1 mm (81.2% of the total annual rainfall); dry period is from April to September, when the rainfall average is 279.3 mm (18.8% of the total annual rainfall).

Rainwater treatment plant

Mid-term investigations related to rainwater quality have been conducted at UNESP, Rio Claro-SP. While arranging the rainwater treatment plant (RTP), Nakada & Moruzzi (2014) assessed the quality of harvested rainwater, over a 2-year period. The results showed collected rainwater requires treatment prior to use, and indicated the need for operationally flexible technologies when treating roof-harvested rainwater, due to its high variability.

The RTP installation was accomplished on the buildings of the Environmental Study Centre at UNESP, Rio Claro-SP (22° 23’ 45.18” S, 47° 32’ 49.18”). The catchment system is derived from a previously installed rainwater drainage system, which pipes the water from the gutters to stormwater bypass boxes, where a leaf screen was placed, and from where rainwater is now gravity-transported to the RTP. The catchment area comprises 400 m², being about 390 m² of ceramic tiled roof and 10 m² of ground.

Figure 1 illustrates the RTP, which consists in direct filtration with hydraulic rapid mixing, and is comprised of: (i) three first flush tanks, which were not used in this study due to technical problems; (ii) rainwater tank, sized 10 m³; (iii) three parallel pressure filters, installed with three different filter media; and (iv) three storage tanks, sized 3 m³ each, being each of these tanks piped from one filter.

The installed pressure filters (F28-R, Mark Grundfos) have 0.06 m² filtration area and 280 mm diameter, with capacity for 25 kg of sand.

According to the suppliers, filter media have the following characteristics: coefficient of uniformity: Sand A: 1.8, Sand B: <1.43, Sand C: 1.41, Anthracite: 1.7; Particle size (mm): Sand A: 0.35–0.80, Sand B: 0.60–1.20, Sand C: 1.50–3.36; Effective particle size (mm): Sand A: 0.52, Sand B: 0.67, Sand C: 1.84, Anthracite: 0.90–1.0. The filling of the filters was accomplished as follow: Filter 1 was completely filled with Sand A. Filter 2 was totally filled with Sand C. Filter 3 has Sand B on the bottom, Sand A on the middle and anthracite on the top layer. All filter media were first placed for this research, and backwash was not carried out.

Figure 1 | Schematic illustration of the RTP used in this study.

Downloaded from https://iwaponline.com/ws/article-pdf/15/6/1326/413387/ws015061326.pdf by guest
Rainwater harvesting, bench-scale tests and full-scale filtration

In this study, direct filtration with hydraulic rapid mixing was performed in nine different configurations. We conducted filtration using three distinct media filters, two coagulants (cationic corn starch and ferric chloride) and one filtration aid (non-ionic corn starch). Corn starch is the target of this research, being ferric chloride inserted in the tests for comparison purposes.

Rainwater was harvested, a first flush was not carried out, and rainwater was filtered with a hydraulic loading rate of 450 m³(m² day)⁻¹, for 1 hour in each filter, and for each coagulant or filtration aid, which were applied by a dosing pump (Alldos Eichler, GmbH).

Prior to full-scale filtration, samples were taken from the rainwater tank to proceed to bench-scale tests in Jar-test equipment, in order to determine the optimal dosage of cationic corn starch, non-ionic corn starch or ferric chloride to be applied in full-scale filtration.

Jar-test experiments were conducted for each rain event, at velocity gradient G = 300 s⁻¹, for 40 s, and immediately after this period, samples were simultaneously filtered in filter paper Whatman® 40 (Sigma–Aldrich®).

We conducted full-scale filtration, applying the concentration of coagulant or filtration aid that promoted higher turbidity removal in bench-scale.

Corn starch stock solution

Cationic corn starch (Cargill, Inc.) and the commercial product ‘Maizena’ (Unilever, Inc.), a non-ionic corn starch, were investigated for rainwater treatment. For both corn starches, the procedure for stock solutions was adapted from Campos & Di Bernardo (1988), according to the following steps: a glass beaker was placed on an analytical balance, which was tared with it; the required corn starch was weighed; the required volume of ultra-pure water to prepare the desired concentration of stock solution was measured, and added to the corn starch; the mixture was stirred continuously, with a glass rod and the solution was heated on a heating plate until it reached 80 °C; finally, the initial volume of the solution was completed with ultra-pure water.

Sample analyses

The water quality parameters quantified and the methods used were: apparent colour (Pt-Co) by Spectrophotometer HACH DR 2800; turbidity (NTU) by Turbidimeter HACH DR 2100P; total coliforms (most probable number, MPN/100 mL) and Escherichia coli (MPN/100 mL) by chromogenic and fluorogenic substrate test (Colilert®); pH (pH units) and temperature (°C) by Multiparameter probe TECNAL TEC-3P-MP.

Statistical analysis

We performed a Mann–Whitney test with a significance level α = 0.05, to evaluate statistically significant differences of removals of turbidity and apparent colour: among filter media for each coagulant or filtration aid; and among coagulants or filtration aid for each filter media.

RESULTS AND DISCUSSION

Characteristics of rain events and harvested rainwater prior to treatment were rainfall (mm): 11.6, 51.8, 13.7; antecedent dry days: 2, 4, 10; apparent colour (Pt-Co): 47.7, 120.3, 40.3; turbidity (NTU): 6.4, 20.0, 3.6; total coliforms (MPN/100 mL): 6.9 × 10³, 240, 5; E. coli (MPN/100 mL): 84, 41, 0.1; pH: 6.2, 6.4, 6.4; temperature (°C): 23.9, 22.5, 21.5.

The turbidity removal efficiencies and the remaining turbidity after bench-scale filtration are shown in Figure 2(a).

The lower and upper limits of turbidity removal efficiencies in Jar-test were 15.5% (1 mg L⁻¹) and 78.4% (6 mg L⁻¹), 14.0% (8 mg L⁻¹) and 82.4% (4 mg L⁻¹), 18% (6 mg L⁻¹) and 56.9% (2 mg L⁻¹), for cationic corn starch; 47.2% (2 mg L⁻¹) and 51.6% (6 mg L⁻¹), 24.7% (10 mg L⁻¹) and 34.3% (4 mg L⁻¹), 51.0% (2 mg L⁻¹) and 64.2% (10 mg L⁻¹), for non-ionic corn starch; 28.8% (1 mg L⁻¹) and 84.7% (3 mg L⁻¹), 49.3% (1 mg L⁻¹) and 88.6% (5 mg L⁻¹), for ferric chloride.

Based on Jar-test results, the dosages (mg L⁻¹) applied in full-scale filtration were cationic corn starch: 6, 4, 2; non-ionic corn starch: 6, 4, 10; ferric chloride: not applied, 3, 5.

The turbidity removals during full-scale filtration are shown in Figure 2(b). When cationic corn starch was applied, the highest turbidity removals were achieved by
Filter 1, and the use of this conjunction enabled meeting the guidelines for turbidity at all times. When turbidity of harvested rainwater was 20 NTU, after 1 hour of filtration, the only strategy which met Brazilian guidelines for turbidity was comprised by Filter 1 and cationic corn starch. When turbidity of harvested rainwater was already low (3.6 NTU), ferric chloride reached the highest removals, with remaining turbidity varying from 0.35 to 0.5 NTU.
nevertheless, cationic corn starch achieved remaining turbidity from 0.74 to 0.87 NTU. Furthermore, after 50 minutes filtration, cationic corn starch obtained remaining turbidity from 0.81 to 0.91 NTU, providing turbidity <1 NTU, meeting guidelines for potable uses. Non-ionic corn starch only provided turbidity for restrictive non-potable uses.

The quantified parameters of water quality after 60-minute direct filtration are shown in Figure 3. In full-scale filtration, cationic corn starch achieved removal efficiencies of apparent colour ≤71.7%, turbidity ≤78%, total coliform ≤1.1 log-unit, E. coli ≤1.6 log-unit; non-ionic corn starch reached removal efficiencies of apparent colour ≤43%, turbidity ≤52%, total coliforms ≤1.0 log-unit, E. coli ≤1.5 log-unit; ferric chloride provided removal efficiencies of apparent colour ≤67%, turbidity ≤88%, total coliforms ≤1.8 log-unit, E. coli ≤3.9 log-units.

Removal efficiencies were lower for apparent colour than for turbidity, indicating remaining colour is due to colloids, which cannot be removed from water by sand filtration, as well as true colour, normally caused by the presence of organic molecules derived from vegetable matter, not from suspended matter (Environmental Protection Agency (EPA) 2002). Harvested rainwater might present colour due to vegetable matter decomposition, which may reach the roof by dry deposition.

The results of turbidity removal by cationic corn starch are consistent with the expected, as turbidity is mostly caused by suspended materials, which are normally negatively charged, thus, resulting in charge neutralisation (Environmental Protection Agency (EPA) 2002).

E. coli removal efficiencies, when corn starches were applied, are in accordance with the literature for direct filtration, up to 1.5 log-unit (Li et al. 2012).

When corn starches were applied, pH was kept >6 at all times. When ferric chloride was applied, pH decreased at all times. These data agree with the results from Jar-test, in which increases in dosage of ferric chloride cause pH decreasing, as expected (Environmental Protection Agency (EPA) 2002).

It is worth mentioning that inorganic coagulants are more effective than polyelectrolytes when water temperature is higher than 12 °C (Environmental Protection Agency (EPA) 2002), as this may explain the slightly higher turbidity removal efficiency reached by the use of ferric chloride compared to cationic corn starch.

In general, results of Mann–Whitney tests (α = 0.05) indicate: for cationic corn starch, filter media do not cause great influence in removal efficiencies of apparent colour, nevertheless, statistically significant differences of turbidity removal could be found, suggesting Filter 1 is potentially more efficient than Filters 2 and 3; for non-ionic corn starch, Filter 1 and Filter 2 have similar behaviour, with no statistically significant differences of removals of apparent colour and turbidity; for ferric chloride, filter media influence removal efficiencies for apparent colour and turbidity. Filter 3 presented statistically significant differences of removals of apparent colour and turbidity, being less efficient for low values of these parameters, and more efficient for high values, when non-ionic corn starch as well as ferric chloride were applied.

**CONCLUSIONS**

Results of this research indicate the proposed strategy is suitable for rainwater treatment, as it can provide a flexible technology. Although the studied treatment had considerably improved roof-harvested rainwater quality, treated water did not meet Brazilian guidelines for non-potable uses, considering remaining E. coli, thus, requiring a disinfection unit. Babu & Chaudhuri (2005) highlighted even a well-designed and maintained system will not usually meet an absence of faecal coliform without a disinfection step.

Cationic corn starch has showed great potential to be used as primary coagulant for rainwater treatment, as it enabled meeting the guidelines for turbidity, even for potable purposes. Referring to filter media, the results here presented pointed out Filter 1 (single-layer sand filter; effective particle size: 0.52 mm) had better performance than the other media, when cationic corn starch was applied as primary coagulant. The use of corn starch provides maintenance of nearly neutral pH in treated water, thus it may be feasible to apply at large scale. Also, utilising corn starch as coagulant has the advantage of availability at low cost. As corn starch is already used with foodstuffs, it is recognised as harmless in water treatment (Environmental Protection Agency (EPA) 2002). Still, further studies are necessary to assess by-products formation, especially if a disinfection unit is used.
Figure 3 | Rainwater quality after 60-minute full-scale filtration.
ACKNOWLEDGEMENTS

The authors are grateful to: the Financier of Studies and Projects (Finep 2198/07) and the National Council for Scientific and Technological Development (CNPq 477102/2007-7 and CNPq 477881/2006-8) for financial aid; the São Paulo State Research Foundation (FAPESP 09/11726-7) for masters fellowship; Cargill, Inc. for supplying cationic corn starch.

REFERENCES


Environmental Protection Agency (EPA) 2002 Water Treatment Manuals – Coagulation, Flocculation & Clarification. Environmental Protection Agency, Wexford, Ireland.


United States Environmental Protection Agency (USEPA) 2008 Managing wet weather with green infrastructure – Municipal handbook – Rainwater harvesting policies.

United States Environmental Protection Agency (USEPA) 2013 Rainwater Harvesting: Conservation, Credit, Codes, And Cost – Literature Review And Case Studies. Environmental Protection Agency, Washington, DC.

First received 13 March 2015; accepted in revised form 19 June 2015. Available online 6 July 2015