Evaluation of a household rooftop rainwater harvesting system in France: qualitative and quantitative monitoring of water used for authorised applications - First results

Evaluation d'un système de récupération d'eau de pluie en maison individuelle (France) : Suivi qualitatif et quantitatif des eaux collectées et distribuées pour les usages autorisés par la réglementation – Premiers résultats

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RÉSUMÉ

Le suivi de la qualité de l'eau de pluie collectée en aval de la toiture d'une maison privée (sud ouest de la France) en vu de l'alimentation des chasses d'eau a été réalisé durant neuf mois. Les échantillons ont été prélevés de façon hebdomadaire en cuve (5 m^3) et en sortie d'un robinet extérieur situé après le système de traitement composé d'une chaussette filtrante (25 µm) et d'un filtre à charbon actif. Le pH, la température, la conductivité, la couleur, la turbidité, les concentrations en anions et en cations, le titre alcalimétrique complet, la dureté totale et le carbone organique total ont été déterminés à l'aide des techniques analytiques classiques. Les germes totaux à 22°C et à 36°C, les coliformes totaux, *Escherichia coli* et les *Entérocoques* ont également été analysés. Les paramètres chimiques et microbiologiques ont montré des variations au cours de l'étude. Globalement, les eaux de pluies collectées présentent une bonne qualité physico-chimique mais ne satisfont pas aux exigences d'une eau potable. Ces eaux comparées à une eau potable du réseau sont caractérisées par de faibles conductivités, dureté et titre alcalimétrique complet. Les trois indicateurs microbiologiques les plus utilisés ont été quantifiés dans la majorité des échantillons révélant ainsi une contamination.

ABSTRACT

The quality of harvested rainwater used for toilet flushing in a private house in the south-west of France was assessed over a nine-month period. Water samples were collected from the tank (5 m^3) and from an outside tap after a pre-treatment process consisting of a 25 µm-filter and an active carbon filter. Temperature, pH, conductivity, colour, turbidity, anions, cations, alkalinity, total hardness and total organic carbon were screened by standard analytical techniques. Total flora at 22°C and 36°C, total coliforms, *Escherichia coli,* and enterococci were analysed. Chemical and microbiological parameters fluctuated during the study. Overall, rainwater collected had good physicochemical quality but did not meet the requirements for drinking water. It is characterised by low conductivity, hardness and alkalinity compared to mains water. The three widely used bacterial indicators, total coliforms, *E. coli* and enterococci were detected in the majority of the samples, revealing microbiological contamination.

KEYWORDS

Hydraulic evaluation, legal non-potable applications, rainwater harvesting system, rainwater quality, roof runoff.

1 INTRODUCTION

Thanks to the EU Water Framework Directive (EU, 2000) implemented to protect the aquatic environment, certain requirements have been set out involving potential use of Rainwater Harvesting. The latter is the process of collecting and storing rainwater for later use, such as toilet flushing, washing machines, garden watering, cleaning purposes, fire fighting, etc. The idea is to avoid using valuable drinking water for flushing toilets by substituting collected roof runoff. However, every European country has adopted a different perspective concerning the use of rainwater due to individual interpretations of the word “domestic” used in the European Directive 98/83/CE. In France, only external uses (garden watering, cleaning, etc.) were allowed, except in special cases (drought, no mains network). Nevertheless, there were already rainwater harvesting devices on the market, which according to suppliers accounted for 10 000 systems in 2007, of which 67 concerned large buildings. Despite reluctance from sanitary authorities (C.S.H.P.F, 2006), the increasing demand from private customers leveraged a reconsideration of rainwater harvesting and a new decree authorised and clarified rainwater use inside buildings in August 2008 (Decree of August 21, 2008).

In Europe, rainwater quality assessment was studied by Förster 1998, Förster 1999, Albrechtsen et al. 2002, Polkowska et al. 2002, Fewtrell at al. 2007, Melidis et al. 2007, Oesterholt et al. 2007, Sazakli et al. 2007, Schriewer et al. 2008, Tsakovski at al. 2010. Other studies focused on hydrological or economic data for rainwater harvesting (Herrmann et al. 1997; Chilton et al. 1999; Fewkes 1999; Fewkes 1999b, Herrmann et al. 1999; Vaes et al. 2001, Villarreal et al. 2005, Nolde 2007). But “a clear consensus on the quality and health risk associated with roof-collected rain-water has not been reached” (Evans et al. 2006), and this literature review draws attention to the need for Research and Development on the hygienic and economic aspects of rainwater harvesting. Thus, the present case study has been carried out to provide scientific data using a commercially available rainwater collection system, installed in south-west of France and monitored over a nine-month period. The objectives were firstly to monitor the rainwater from the roofs, the tank and a tap outside a house, in order to provide scientific data on physicochemical and microbiological quality and secondly, to collect data on hydraulic aspects linked to roof-runoff harvesting.

2 MATERIAL AND METHODS

2.1 Rainwater harvesting system and instrumentation

A commercially available domestic rainwater collection system was installed in a rural area of south west of France. Rainwater is first collected from the 204 m^2 surface area tiled roof of a private house. This water is then channelled via open zinc gutters and downpipes to a wire filter with a mesh before entering into an underground, 5m^3 capacity PEHD storage tank, through a calm inlet. Any overflow is fed into a nearby canal. A pumping system using a submerged (approximately 0,10 m) intake with an inlet filter attached to a float, then pumps water inside the house, through a treatment process composed of a 25µm filter and an active carbon filter. UV radiation water treatment may also be carried out but was not used in this initial study. When insufficient water is available in the tank, a probe activates a valve to allow pumping from a backup drinking water tank. Rainwater collected is available for toilet flushing and garden watering for a household of four and can supply two WCs and an outside tap.

The device also includes a rain gauge with swinging runnels, a water flow monitoring system, a probe to measure water tank level, a triangular weir, a flow meter to measure the volume evacuated via the overflow, and a central processing unit monitoring parameters every 15 minutes.

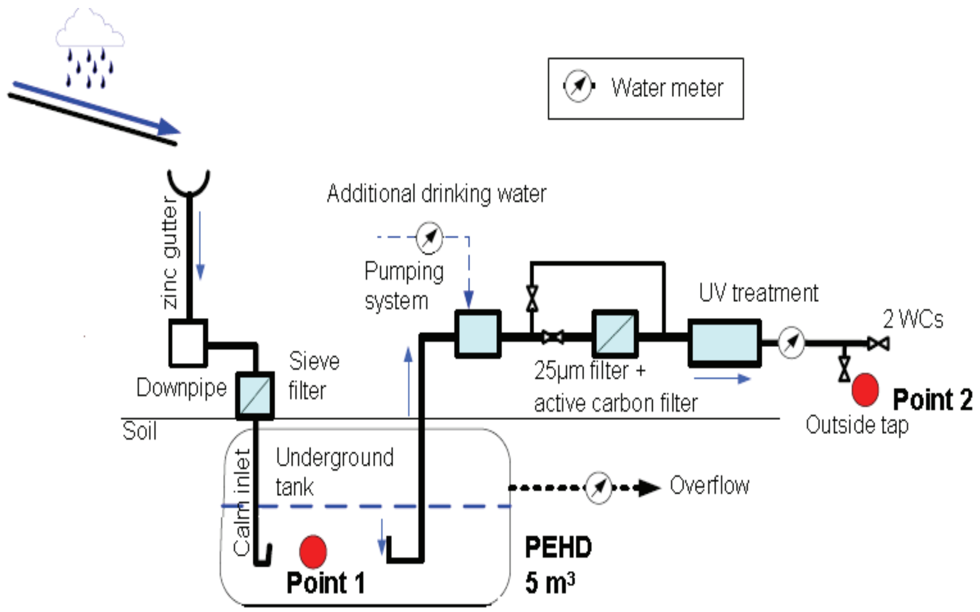

Figure 1. Plan of rainwater harvesting system

2.2 Sampling and measurements

Sampling was carried out from January 2009 to September 2009. Water samples were collected weekly from the tank (Figure 1, point 1) and from the outside tap (Figure 1, point 2). Concerning point 1, grab samples were taken from the surface of the tank using a sampling rod and beaker, the latter having previously been disinfected with ethanol and rinsed with UHQ water once and with tank water twice. Concerning point 2, samples were taken after water had been run to waste for at least one minute and after disinfection of the tap with ethanol. All samples were placed in polyethylene bottles for chemical analysis or individual sterile bottles for microbiological analysis, and transported to the laboratory in a chilled cold-box. Temperatures of the samples were measured *in situ* before transfer. Samples were stored at 4°C and assessed within 24h for microbiological analysis or frozen to await chemical analysis.

Samples were analysed in accordance with the norm shown in Table 1. The ionic composition was analysed by ion chromatography (Dionex, AG/AS 18, ICS 2000 for anions and CG/CS 12, ICS 3000 for cations).

Parameter	**Norm**	Mg^{2+}, Ca^{2+}, Na^{+}, K^{+}, NH_4^{+}	NF EN ISO 14911
pH	NF T 90-008	Colour	NF EN ISO 7887
Conductivity	NF EN 27888	Total organic carbon	NF EN 1484
Turbidity	NF EN ISO 7027	Total hardness	NF EN ISO 14911
Cl^{-}, SO_4^{2-}, NO_3^{-}, PO_4^{3-}	NF EN ISO 10304-1	Alkalinity	NF EN ISO 9963-1

Table1. Physico-chemical parameters analyzed

The microbiological water quality was monitored using the relevant ISO (International Organization for Standardization) standards. ISO 6222 for total flora at 22°C and 36°C, ISO 9308-1 for total coliforms and *Escherichia coli,* and ISO 7899-2 for enterococci.

3 RESULTS AND DISCUSSION

3.1 Qualitative analysis

3.1.1 Physicochemical analysis

The average, maximum, minimum and median values of parameters for rainwater collected in the tank are shown in Table 2. The measured values were compared to French Drinking Water Guidelines (Decree of 11 January 2007). The temperature of the samples ranged from 8.3°C to 22.4°C, which was within the range of outside air temperatures recorded, since sampling began in winter and ended in September. A pH range of 5.6 - 10.4 was recorded in the tank. In fact, extreme alkaline values were observed after exceptional weather, e.g. after a violent storm a peak of 10.4 was found, which took five weeks to return to a slightly acid value. Apart from these extremes, pH ranged from 5.6 to 6.9. By comparison, ranges found in the literature for Europe, indicate run-off water pH as : 6.0 - 8.2 (Villarreal et al. 2005); 7.6 – 8.8 (Sazakli et al. 2007) and 5.8 - 8.4 (Schriewer et al. 2008). Concerning colour and turbidity, around two-thirds of results exceed limit values for drinking water, 15 mg Pt/L and 2 NTU respectively. Ion concentrations were low, for example 84% of conductivity values were lower than 100 µS/cm, revealing a low mineralisation of harvested rainwater. All concentrations comply with the guidelines except for ammonia that often exceeded them. Analyses reveal low aggressive water in the system.

Results for samples from the outside tap were similar except when the system was working with a supply of drinking water. Mains water has a pH of about 7.5 and higher values of conductivity, hardness, and alkalinity. These parameters could be used as switching indicators to show when the system is not functioning with rainwater because of a lack of supply in the tank.

The chemical quality of harvested and stored rainwater in this area of France is quite good, but some parameters were detected above the corresponding maximum allowable concentrations for drinking purposes.

Parameter	Unit	n	min	max	mean	median	French Drinking Water Guidelines
pH	-	38	5.6	10.4	6.7	6.3	6.5 to 9
Temperature	°C	38	8.3	22.4	15.6	16.0	25
Conductivity	µS/cm	38	15.8	235.0	66.5	46.7	180 to 1000
Turbidity	NTU	36	0.5	6.1	2.8	2.9	2
Colour	mg Pt/L	38	<5	36.0	17.4	19.5	15
TOC	mg/l	37	1.1	5.1	2.6	2.4	
Hardness	mmol/l	38	0.1	0.6	0.2	0.1	
TA	mmol/l	38	<0.2	0.5	<0.2	<0.2	
TAC	mmol/l	38	<0.40	1	0.3	0.4	
Cl-	mg/L	20	0.6	4.0	2.6	2.8	250
SO_4^{2-}	mg/L	20	0.9	3.0	1.9	2.2	250
NO_3^-	mg/L	20	1.5	7.8	3.6	2.9	50
PO_4^{2-}	mg/L	20	<0.1	0.5	0.1	0.1	
Mg^{2+}	mg/L	20	0.1	0.7	0.3	0.4	
Ca^{2+}	mg/L	20	1.5	18.7	7.5	6.7	
Na^+	mg/L	19	0.3	2.3	1.4	1.6	200
K^+	mg/L	20	0.3	4.9	2.2	2.8	
NH_4^+	mg/L	19	<0.1	1.5	0.4	0.3	0.10

Table 2. Physico-chemical composition of tank water

3.1.2 Microbiological analysis

Microbiological composition of water in the tank and from the outside tap was variable. Results are shown in Table 3 with ranges, and on Figure 2 with distribution of values. Total flora gives a measure of the total bacterial load. Counts at 22°C range from 10 to 6.32×10^5 organisms per mL in the tank and from 26 to 2.28×10^5 organisms per mL from the outside tap. Almost all samples were contaminated with coliforms, i.e. they exceeded zero organisms per 100 mL. Only 5 tap samples of the 35 gave negative (zero) counts. Total coliforms were indicative of an environmental contamination and provide a measure of possible faecal contamination. Two faecal indicators were also monitored and analyses showed varying degrees of contamination in the different samples. Roof-collected rainwater often shows high levels of contamination in enterococci, as can be seen from the maximum values of 850 and 950 CFU/100mL. A positive *E. coli* count was recorded in 74% of tank samples and 44% of tap samples which indicates faecal contamination. These results indicate a risk of pathogens.

The three widely used bacterial indicators, total coliforms, *E. coli* and enterococci were detected in the majority of samples. Our results agree with previous studies (Albrechtsen 2002; Blangis et al. 2007; Nolde 2007; Sazakli et al. 2007). They show that roof run-off has poor, microbiological drinking quality. To complete these first results, other parameters less present in the literature will be analysed; *Cryptosporidium* oocysts, *Giardia* cysts, *Aeromonas*, *Pseudomonas Aeruginosa*, *Legionella*, etc.

			Tank			Outside tap after filtration		
Parameter		N	illegible	legible		illegible	legible	
				Min	Max		Min	Max
Total coliforms	CFU/100mL	35	11	10	10 000	9	0	1 300
E. coli	CFU/100mL	34	-	0	230	-	0	130
Enterococci	CFU/100mL	35	-	1	850	-	0	930
Total flora 22°C	CFU/mL	33	-	10	632 000	-	26	228 000
Total flora 36°C	CFU/mL	32	-	25	368 000	-	26	192 000

Table 3. Microbiological results

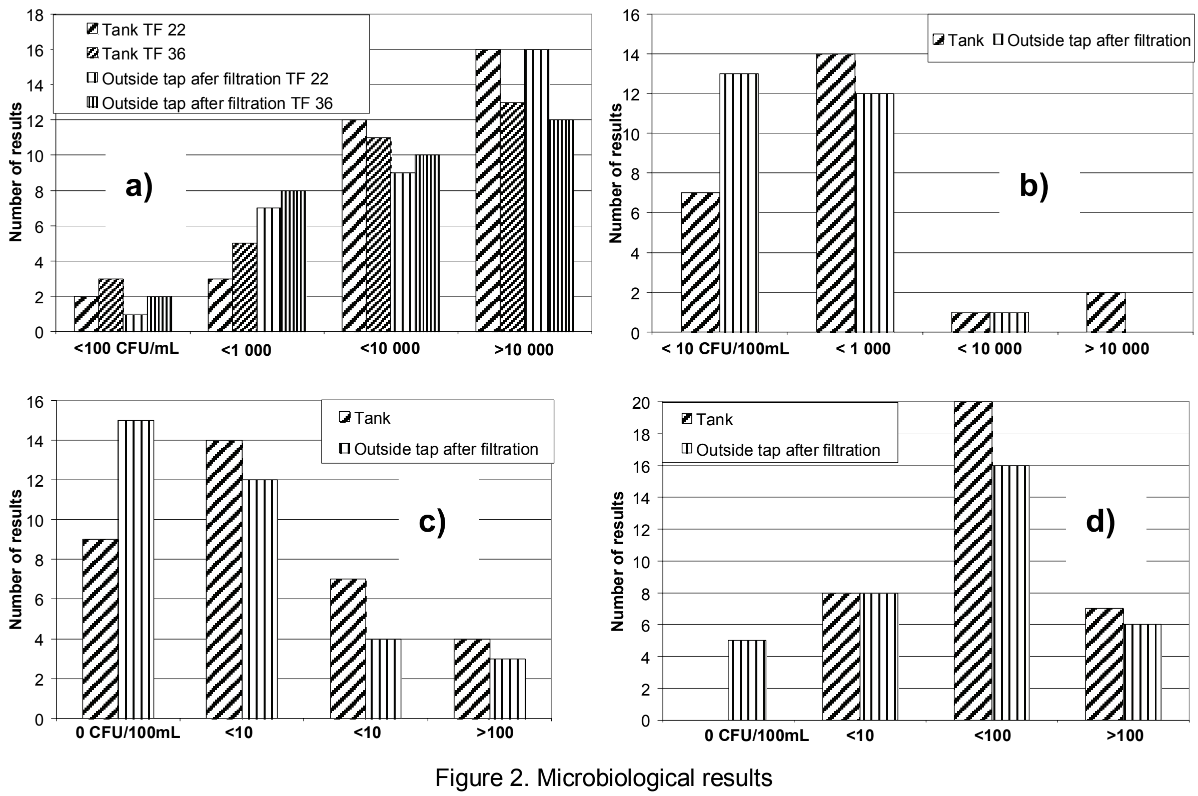

Figure 2. Microbiological results

a) Total flora at 22°C and 36°C - b) Total coliforms - c) *E. coli* - d) Enterococci

3.2 Quantitative analysis

Concerning the hydrological part, the quantitative monitoring began in March 2009 and the results of the first months of operation thus represent a household in rural south-west France with an annual rainfall of about 670 mm. The family has an average daily consumption for toilet flushing of 120L i.e. 30L per day per inhabitant, representing 20% of total consumption. The volume of rainwater stored and the volume supplied by the mains water network for toilet flushing was also investigated. The study showed that 11 m^3 were used for toilet flushing within the 3 months spring period which had a rainfall of 168 mm. In fact, 10 m^3 of rainwater was stored and the volume remaining was supplied from the mains network (around 8%).

4 CONCLUSIONS

There is no consensus or common practice within Europe concerning Rainwater Harvesting. Moreover, the lack of feedback concerning sanitary issues does not encourage some countries to develop it. However, conclusions on water quality may be drawn from this study in which the performance of a rainwater collection system has been monitored weekly over a period of nine months. Firstly, harvested rainwater has good physicochemical quality but does not meet drinking water standards. Secondly, the results of this survey are in keeping with a number of other studies and show that roof-collected rainwater makes poor quality drinking water overall, with regard to bacteriological indicators. Using rainwater introduced micro-organisms, not usually present in mains water, into the household. As a consequence, a complementary study with the use of UV-treatment will be carried out, and anyway, it would appear necessary to investigate sanitary risks of rainwater use.

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