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# Recycled vertical flow constructed wetland (RVFCW)—a novel method of recycling greywater for irrigation in small communities and households

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**Abstract**

The use of greywater for irrigation is becoming increasingly common. However, raw greywater is often contaminated and can cause environmental harm and pose health risks. Nevertheless, it is often used without any significant pretreatment, a practice mistakenly considered safe. The aim of this study was to develop an economically sound, low-tech and easily maintainable treatment system that would allow safe and sustainable use of greywater for landscape irrigation in small communities and households. The system is based on a combination of vertical flow constructed wetland with water recycling and trickling filter, and is termed recycled vertical flow constructed wetland (RVFCW). The RVFCW's properties, removal efficiency, hydraulic parameters and feasibility were studied, as well as the environmental effects of the treated greywater, as reflected by soil and plant parameters over time. The RVFCW was efficient at removing virtually all of the suspended solids and biological oxygen demand, and about 80% of the chemical oxygen demand after 8 h. Fecal coliforms dropped by three to four orders of magnitude from their initial concentration after 8 h, but this was not always enough to meet current regulations for unlimited irrigation. The treated greywater had no significant negative impact on plants or soil during the study period. The feasibility analysis indicated a return over investment after approximately three years. We concluded that the RVFCW is a sustainable and promising treatment system for greywater use that can be run and maintained by unskilled operators.


*Keywords:* Vertical flow constructed wetland; Wastewater reuse; Greywater treatment; Environmental pollution

## 1. Introduction

The quantity of freshwater available worldwide is declining, raising the pressing need for its more efficient use. One method of conserving water is by recycling greywater (GW) for irrigation. GW is domestic wastewater that includes only wash water (i.e., bath, dish, and laundry water), whereas blackwater consists of toilet water. Due to the substantial difference in their qualities, separating GW and blackwater would provide for more effective wastewater treatment, allowing a large volume of water to be efficiently recycled (Lindstrom, 2000). This is particularly important in arid zones, were water is scarce and recycling GW for private and public landscape irrigation could reduce potable water use by up to 50% (DHWA, 2002). The use of GW for private garden irrigation is becoming increasingly common. In most countries, regulations or specific guidelines for GW reuse are not available, and it is therefore often used without any significant pretreatment, a practice mistakenly considered safe. In countries such as the USA and Australia, where regulations for the use of GW have been established, they concentrate on issues associated with public health but do not consider potential harmful environmental impacts (Dixon et al., 1999; DHWA, 2002; ADEQ, 2003). The separation of the

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toilet stream from domestic wastewater generates effluents which have reduced levels of nitrogen, solids, and organic matter (especially the barely degradable fraction), but often contain elevated levels of surfactants, oils, boron and salt. The components in GW may alter soil properties, damage plants and contaminate groundwater (Garland et al., 2000; Gross et al., 2005; Wiel-Shafran et al., 2006). A study aimed at applying commercial systems to GW reuse in households demonstrated, in five different commercial systems, failure to treat the GW sufficiently for unlimited use (Gross et al., 2003). That study also suggested that this was so, either because the treatment was too superficial (as the water is considered safe by many), or because it was a downscaled wastewater treatment system rather than a GW treatment system aimed at treating small volumes in private houses.

The aim of the current study was to develop an economically sound, low-tech and easy-maintenance treatment system that would allow safe and sustainable use of GW for landscape irrigation in small communities and households.

## 2. Materials and methods

### 2.1. Recycled vertical flow constructed wetland

The proposed treatment method is a modification of the vertical flow constructed wetland (VFCW) described by IWA (2000), with a novel set-up. Initially, the system was composed of two containers (0.95 m W × 0.95 ml × 0.55 mH; about 500 l each) placed one above the other: (1) the upper one was a VFCW composed of a three-layer bed consisting of 15 cm planted organic soil over a 30 cm layer of tuff or plastic media and a 5-cm lower layer of limestone pebbles. The bottom of the bed's compartment was perforated; (2) the lower container was used as a water reservoir, located directly beneath the VFCW (Fig. 1).

The raw GW flowed through a sedimentation tank which accounted for about 10% of the total system volume and where only coarse material settled. From this tank it was pumped or overflowed into the root zone of the VFCW plants, and then it trickled down through the three-layer filter bed to the reservoir. A centrifuge pump continuously recycled the GW at a known rate from the reservoir back to the VFCW. The treated water was then used for irrigation directly or following a secondary sedimentation. An overflow pipe was set from the upper wetland container to the reservoir to prevent overflow in case of the wetland clogging.

### 2.2. Recycled vertical flow constructed wetland performance

The Recycled vertical flow constructed wetland (RVFCW) properties, removal efficiency and hydraulic parameters were studied in a short-term study, a 3-month "batch" greenhouse study and a long-term case study. All the studies were conducted after three months of a continuous working period. This procedure ensured the development of bio-film in the wetland and stabilization of the system performance in terms of removal efficiency and flow.


Fig. 1. Recycled vertical flow constructed wetland (RVFCW). (A) vertical flow constructed wetland, (B) reservoir, (C) recycling pump, and (D) demonstration of filter media layers (peat, tuff or high surface area plastic media, and lime pebbles in top middle and bottom layers, respectively).

#### 2.2.1. Short-term study

In the beginning of the study, the pore volume of the filter section and the treated water reservoir were emptied and 300 l of fresh GW was introduced into the VFCW (at the root zone). A subsample of the raw GW was collected for analysis (time zero). The GW was continuously recycled between the reservoir and the VFCW at a known rate of 390 l h$^{-1}$, determined by a water meter that was attached to the system. Samples of the treated GW were taken immediately after it initially passed the bed and then after 2, 4, 8, 12, 24, and 48 h. Samples were analyzed for: total suspended solids (TSS), total phosphorus (TP), total nitrogen (TN), anionic surfactants measured as methylene blue-active substances (MBAS), dissolved oxygen (DO), electrical conductivity (EC), pH, 5-day biological oxygen demand (BOD), chemical oxygen demand (COD), and total boron (TB). Water-quality analysis followed standard procedures (APHA, 1998); fecal coliforms (FC) and total coliforms were measured by the plate count technique (Merck, 2000).

#### 2.2.2. "Batch" greenhouse study

The RVFCW was used to evaluate the environmental effects of treated GW on plants and soils in comparison