JULIANO REZENDE MUDADU SILVA

REUSO DIRETO DE ÁGUA CINZA NA AGRICULTURA: PERCEPÇÃO DE EXTENSIONISTAS RURAIS E PROPOSTA DE DIMENSIONAMENTO DE CÍRCULO DE BANANEIRAS

Dissertação apresentada à Universidade Federal de Viçosa, como parte das exigências do Programa de Pós-Graduação em Agroecologia, para obtenção do título de *Magister Scientiae*.

Orientador: Raphael B. A. Fernandes

Coorientador: Alisson Carraro Borges

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APROVADA: 08 de novembro de 2021.

Assentimento:

Juliano Rezende Mudadu Silva
Autor

Raphael Bragança Alves Fernandes
Orientador

Dedico este trabalho a todos aqueles que acreditam no reencontro consciente da humanidade com a natureza e que defendem uma sociedade mais justa e saudável.

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"Giro o mundo, viro, reviro...Voo entre as estrelas, brinco de ser uma...Rezo com as três Marias. Vou além, me recolho no esplendor das Nebulosas".

(Maria Bethânia em Carta de Amor)

RESUMO

SILVA, Juliano Rezende Mudadu, M.Sc., Universidade Federal de Viçosa, novembro de 2021. **Reuso direto de água cinza na agricultura: percepção de extensionistas rurais e proposta de dimensionamento de Círculo de Bananeiras**. Orientador: Raphael Bragança Alves Fernandes. Coorientador: Alisson Carraro Borges.

O estudo foi motivado pelo direito humano ao acesso ao saneamento seguro, pela sustentabilidade da segurança hídrica, alimentar e nutricional e pelo desenvolvimento de sistemas agroalimentares mais resilientes. O objetivo geral foi investigar e contribuir com as estratégias para o uso sustentável da água cinza como recurso hídrico alternativo com a abordagem do saneamento ecológico, dentro de uma proposta de integração do saneamento à agricultura na recuperação de recursos. O estudo foi dividido em dois capítulos. O primeiro capítulo teve como objetivos propor um modelo de dimensionamento de um projeto padrão para o sistema Círculo de Bananeiras, baseado no conceito de balanço hídrico, os fluxos de água cinza, chuva, infiltração e evapotranspiração. O dimensionamento do sistema considerou as áreas necessárias para os fenômenos da infiltração e evapotranspiração. Na determinação da área de infiltração foi considerada uma vala de forma cilíndrica, sendo determinadas a taxa de carga hidráulica e a taxa de percolação do solo. A taxa de evapotranspiração das bananeiras foi considerada na definição da área de evapotranspiração. Uma simulação teórica foi efetuada considerando a produção de água cinza por uma família de cinco pessoas, vivendo em um contexto de baixa renda e com escassez de água. Os resultados indicaram o potencial do modelo proposto para fornecer critérios para o projeto padrão. O segundo capítulo objetivou avaliar a aceitação e percepção de riscos e benefícios de técnicos de assistência rural de Minas Gerais para o reuso da água cinza como recurso hídrico alternativo na agricultura. Os resultados indicaram atitude positiva dos entrevistados em relação ao reuso da água cinza na agricultura. Mais de 80% dos técnicos acreditam na possibilidade de utilizar a água cinza como um recurso hídrico alternativo e apresentam disposição de realizar a prática. Apesar da percepção de possíveis riscos à saúde humana com a ingestão de alimentos crus, a maioria dos entrevistados acredita que é possível realizar o reuso de forma segura com a adoção de técnicas de irrigação e tratamento no local. Uma perspectiva positiva para o desenvolvimento de políticas públicas para o reuso de água no estado foi percebida entre os técnicos, especialmente nas regiões com histórico de escassez hídrica e em um contexto socioeconômico mais precário. Este estudo oferece contribuições às discussões relacionadas ao reuso da água na agricultura e subsídios para o desenvolvimento de políticas públicas de reutilização de águas residuárias.

Palavras-chave: Reuso. Evapotranspiração. Permacultura. Saneamento Ecológico.

ABSTRACT

SILVA, Juliano Rezende Mudadu, M.Sc., Universidade Federal de Viçosa, November, 2021. **Direct greywater reuse in agriculture: perception of rural extension workers and a proposal for the Banana-Tree Circle design**. Advisor: Raphael Bragança Alves Fernandes. Co-advisor: Alisson Carraro Borges.

The study was motivated by the human right to access to safe sanitation, the sustainability of water, food and nutrition security and the development of more resilient agricultural systems. The overall objective was to investigate and contribute to strategies for the sustainable use of greywater as an alternative water resource with the ecological sanitation approach, within a proposal to integrate sanitation with agriculture in the recovery of resources. The study was divided into two chapters. The first chapter aimed to propose a model for sizing a standard design for the Banana-Tree Circle system, based on the concept of water balance, considering the flows of greywater, rainfall, infiltration and evapotranspiration. The design of the system considered the areas necessary for the processes of infiltration and evapotranspiration. In determining the infiltration area, a cylindrical shaped trench was considered, and the hydraulic loading rate and soil percolation rate were determined. The evapotranspiration rate of the banana plants was considered for the definition of the evapotranspiration area. A theoretical simulation was performed considering the greywater production of a family of five, living in a low-income and in a water-scarce context. The results indicated the potential of the proposed model to provide criteria for standard design. The second chapter aimed to evaluate the acceptance and perception of risks and benefits of rural assistance technicians in Minas Gerais for the reuse of greywater as an alternative water resource in agriculture. The results indicated a positive attitude of the interviewees towards the reuse of greywater in agriculture. More than 80% of the technicians believe in the possibility of using greywater as an alternative water resource and are willing to perform the practice. Despite the perception of possible risks to human health with the ingestion of raw food, most of the interviewees believe that it is possible to perform the reuse in a safe way with the adoption of on-site irrigation and treatment techniques. A positive perspective for the development of public policies for water reuse in the state was perceived among the technicians, especially in regions with a history of water scarcity and with a more precarious socioeconomic context. This study offers contributions for the discussions related to water reuse in agriculture and subsidies for the development of public policies for effluent reuse.

Keywords: Reuse. Evapotranspiration. Permaculture. Ecological Sanitation.

SUMÁRIO

INTRODUÇÃO GERAL

O mundo tem enfrentado episódios cada vez mais comuns de escassez de água, afetando regiões e países inteiros. Pelo menos um mês por ano, cerca de quatro bilhões de pessoas sofrem com a falta de água no planeta (Mekonnen et al., 2016). Fatores como as mudanças climáticas, consumo crescente, desperdício e o descarte inseguro de águas residuais contribuem para a redução do acesso à água em quantidade e qualidade. Associado ao problema hídrico, o acesso a saneamento seguro e sustentável ainda segue sendo um grande desafio em países de menor renda. Estratégias para o desenvolvimento de soluções que sejam economicamente viáveis e ambientalmente seguras para se garantir o direito humano à água e ao saneamento são, portanto, essenciais, com especial importância em locais mais vulneráveis.

O cenário de crise na disponibilidade de recursos hídricos pode favorecer a criação e consolidação de programas de gestão mais sustentáveis de água, e capazes de enfrentar os desafios oriundos na escassez. Neste sentido e mais recentemente, no Brasil tem se verificado a ampliação do debate acerca da falta de diretrizes governamentais para o uso de águas residuais tratadas para fins agrícolas. Tal discussão é coerente com a atualidade e aderente ao conceito aceito globalmente da possibilidade do reuso seguro de água. Este conceito é inclusive indicado nos Objetivos do Desenvolvimento Sustentável (ODS) como uma das estratégias emergentes para o direito humano ao acesso à segurança hídrica, sanitária, alimentar e nutricional (UN, 2015; Werner et al., 2009; Harvey, 2008).

O reuso de águas vem sendo comumente aplicado em diferentes contextos como uma prática altamente vantajosa para a conservação da água e manutenção da vida. Isto pode ser especialmente importante e com menos riscos quando se utiliza a água cinza, aquele efluente residencial proveniente de pias, chuveiro, lavanderia e cozinha (Yoonus and Al-Ghamdi, 2020). Os benefícios do reuso da água cinza como fonte hídrica alternativa incluem a conservação da água potável local para propostas mais essenciais, a proteção dos recursos hídricos, a redução da carga de esgoto em unidades de tratamento, a recuperação de nutrientes e ganhos de produção vegetal, além da recarga das águas subterrâneas. Em contextos da agricultura familiar, tal reuso pode contribuir, especialmente em regiões com maior déficit hídrico, com maior resiliência de sistemas agroalimentares (Bakare et al., 2015; Oh et al., 2018; Oteng-Peprah et al., 2018; Shi et al., 2018).

A prática do reuso da água cinza na agricultura é orientada pela filosofia do saneamento ecológico de integração, que conecta o saneamento à agricultura (Hu et al., 2016; Langergraber et al., 2005). O saneamento ecológico segue o princípio da eliminação do rejeito para a recuperação da matéria, buscando assim transformar resíduos domiciliares em potenciais e valiosos recursos (Werner et al., 2009). O reuso local da água cinza na agricultura revela ainda novos paradigmas e exige a mudança da percepção humana sobre a reutilização dos seus resíduos.

Quando comparada com as demais águas residuais, a água cinza apresenta em sua composição reduzidas concentrações dos constituintes típicos de águas residuais, o que favorece o gerenciamento seguro mais simplificado e a disposição e reuso na agricultura (Boano et al., 2020; Pradhan et al., 2019; Arden and Ma, 2018; Maimon and Gross, 2018). Apesar disso, os riscos do reuso de água cinza não devem ser desconsiderados. O uso inadequado do reuso de água cinza pode causar efeito negativo para a saúde humana, solo e água subterrânea, por conter patógenos, sais, óleos & graxas, e químicos (Morel et al., 2006).

O reuso doméstico de água cinza não é novidade no Brasil. Projetos bem-sucedidos, como o "Bioágua Familiar", são disseminados e bem aceitos por agricultores familiares na região semiárida, onde historicamente o sertanejo convive com a seca (Santiago et al., 2015). O Ministério da Saúde brasileiro, por meio da Fundação Nacional de Saúde (Funasa), difunde alternativas sustentáveis de saneamento, dentre as quais se inclui o Círculo de Bananeiras (FUNASA, 2018; FUNASA, 2015). Este é um sistema de baixo custo para o manejo local da água cinza utilizando processos naturais de tratamento. Além dessas iniciativas, recentemente o Brasil formulou o Programa Saneamento Brasil Rural (PSBR) que estabelece um plano nacional para o acesso seguro ao saneamento incluindo ações estruturantes, de gestão de serviço, difusão de tecnologias e participação social (BRASIL, 2019).

Nesta perspectiva, a água cinza torna-se um valioso recurso para o cultivo, especialmente em lugares onde ocorre a escassez de água. Tais iniciativas estão ainda em acordo com a Agenda 2030, pois são ferramentas para o planejamento local e regional, com impacto direto e relevante na implementação de políticas públicas baseadas nos objetivos prioritários dos governos e atores locais (UN, 2015).

A adoção de experiências bem-sucedidas em outros territórios pode ser um grande desafio, especialmente quando se trata de novos procedimentos de saneamento. Conhecer a aceitação da população em relação ao reuso da água cinza na agricultura é crucial para orientar as políticas públicas e a tomada de decisões pelos agentes governamentais. Esse entendimento justifica o desenvolvimento de pesquisas dedicadas à aceitação social e percepções dos riscos e benefícios das práticas de reuso de água cinza.

Especificamente em relação ao Círculo de Bananeiras e dentro do contexto da disseminação de soluções sustentáveis, não se verifica até o momento um projeto padrão para esta técnica que considere parâmetros típicos de engenharia que possam garantir a eficiência e a sustentabilidade da prática. Portanto, existem lacunas técnico-científicas no uso dessa tecnologia, pelo predomínio de dimensionamentos empíricos. Tal situação pode colocar em risco a qualidade do lençol freático, principalmente em um cenário onde a capacidade de evapotranspiração das plantas ou infiltração no solo são subestimados. Disto resulta a necessária atenção por parte dos pesquisadores para procurarem contribuir na validação do Círculo de Bananeiras com técnica de saneamento e na sua aceitação em maior escala.

O presente estudo é motivado pelo direito humano ao acesso ao saneamento seguro, pela sustentabilidade da segurança hídrica, alimentar e nutricional e pelo desenvolvimento de sistemas agroalimentares mais resilientes. Diante de todo o exposto, o objetivo geral do estudo foi contribuir com as estratégias de saneamento ecológico para o uso sustentável da água cinza como recurso hídrico alternativo ao investigar a percepção de extensionistas rurais e propor o dimensionamento do Círculo de Bananeiras. Para isto, o estudo foi dividido em dois capítulos.

No primeiro capítulo, intitulado “Acceptance and perception from professionals of rural technical assistance concerning the use of greywater as a water resource in agriculture”, o foco também foi em duas questões de pesquisa: (1) Qual é a aceitação do reuso da água cinza na agricultura; (2) qual é a perspectiva para o desenvolvimento de políticas públicas para o reuso da água cinza. Neste capítulo foi avaliada a aceitação e percepção dos riscos e benefícios do reuso da água cinza na agricultura e os incentivos e desafios para o desenvolvimento de uma política pública para esta prática no estado de Minas Gerais, na visão de técnicos de extensão rural.

No segundo capítulo, intitulado “Design model of Banana-Tree Circle as a nature-based solution for a sustainable greywater management”, busca-se responder duas questões de pesquisa: (i) como o projeto de dimensionamento do Círculo de Bananeiras poderia ser padronizado enquanto otimiza os mecanismos físicos e bioquímicos de tratamento de águas residuárias; (ii) o que deve ser levado em conta para que o Círculo de Bananeiras seja considerado como uma tecnologia viável para o meio rural e em cenários de emergência e de crise humanitária. O modelo de dimensionamento visa tornar-se uma ferramenta essencial para validar, divulgar e facilitar a implementação do Círculo de Bananeiras como uma solução de baixo custo e sustentável para o gerenciamento doméstico de águas cinzas e a conservação de recursos hídricos.

Toda a pesquisa foi orientada visando contribuir para ampliar as discussões relacionadas à reutilização da água na agricultura e, ao mesmo tempo, buscar fornecer subsídios para o desenvolvimento de políticas públicas de reutilização de águas residuárias.

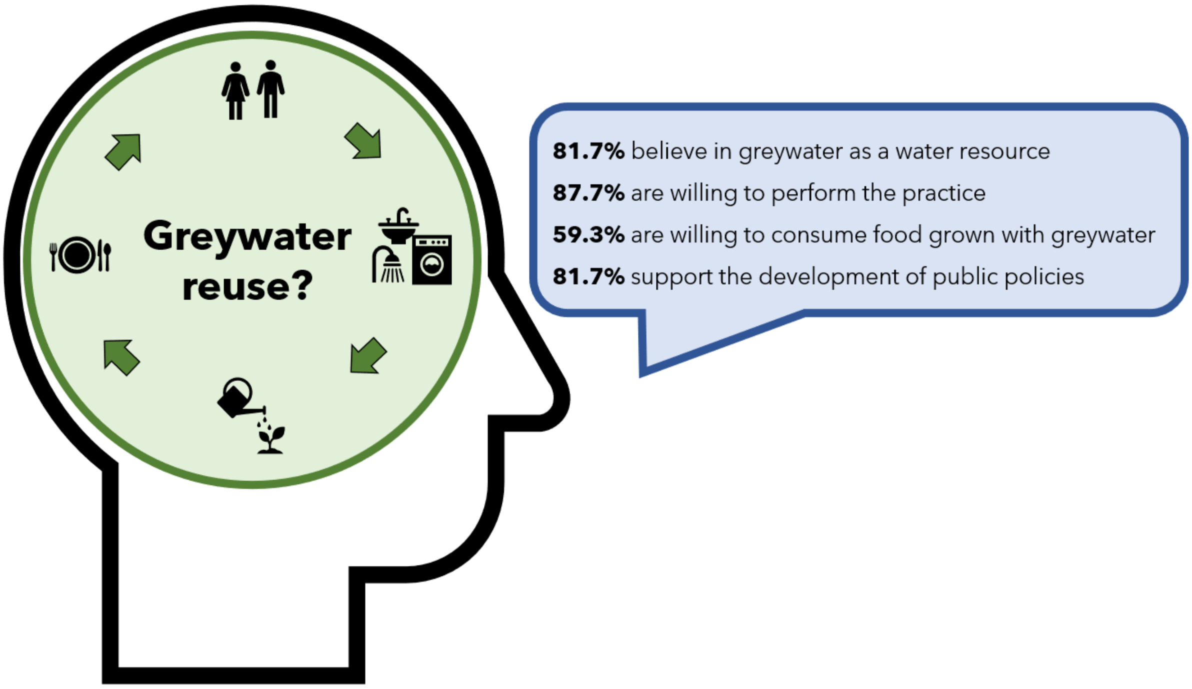
CAPÍTULO 1

Acceptance and perception from professionals of rural technical assistance concerning the use of greywater as a water resource in agriculture

ABSTRACT: Greywater reuse for agricultural purposes can contribute to water conservation and the resilience of family farming food systems, especially in regions with higher water deficits. However, the social acceptance of this practice has been poorly evaluated systematically. This study investigates the acceptance and perception of risks and benefits by 300 professionals of rural technical assistance in Minas Gerais, Brazil, concerning the reuse of greywater as an alternative water resource in agriculture. In general, the surveyed public showed a positive attitude toward reusing greywater in agriculture: 81.7% believe in the possibility of reusing greywater as an alternative water resource; 87.7% are willing to perform the practice, and 59.3% are willing to consume food grown with greywater. Most interviewees believe that it is possible to perform the practice safely with the adoption of irrigation and treatment techniques on site. These findings show the positive acceptance of the practice by this public. The study identified that 81.7% of the interviewees support the development of public policies for water reuse in the state, especially in regions with a history of water scarcity and more precarious socio-economic contexts. This study offers contributions to the discussions about water reuse in agriculture and subsidies for developing of public policies for wastewater reuse.

Keywords: Water scarcity. Greywater reuse. Food systems resilience. Public policies. New ecological paradigm.

Graphical Abstract



Highlights

- Acceptance and perception of risks and benefits of greywater use in agriculture are evaluated
- Positive attitude toward the use of greywater in agriculture by rural technical assistance professionals
- Most professionals believe in the use of greywater as a water resource and are willing to reuse it
- Perception of possible risks to human health are related to the ingestion of raw foods
- Most professionals believe that treatment and irrigation techniques allow the safe practice

1. Introduction

The increasing episodes of water scarcity worldwide are of concern, and for at least one month a year, 4 billion people are affected (Mekonnen et al., 2016). Brazil has also faced successive water scarcity crises in the last years (Targa et al., 2015). Factors as climate change and the unsafe disposal of wastewater contribute to the scarcity of quality water (WHO, 2009), directly affecting the water supply for human consumption, industry and agricultural irrigation in many regions (Coelho et al., 2016).

The scenario of exacerbation of water resources favors the creation of more sustainable water management programs to address the challenges faced in scarcity (Esrey, 2002). Especially those for alternative water sources in irrigated agriculture, responsible for the 70% of the water use in the world and in Brazil (BRASIL, 2017; FAO, 2017). The use of treated wastewater for agricultural purposes is part of the debates of decision-makers in Brazil (BRASIL, 2010). There is a gradual increase of governmental guidelines for this practice, as verified in the states of São Paulo, Ceará, and Minas Gerais (SÃO PAULO, 2017; CEARÁ, 2016; MINAS GERAIS, 2020).

The non-potable reuse of greywater (wastewater from showers, laundries, and kitchens) is also presented globally as an alternative to local drinkable water conservation for more essential proposes (Radingoana et al., 2020; Maimon et al., 2018). For the agricultural purposes, the greywater reuse can also contribute to increase the crop production and resilience of family farming food systems, especially in higher water deficit regions. The domestic use of greywater in agriculture is disseminated in Brazil in projects well accepted by family farmers in the semi-arid region, where they historically coexist with drought (Santiago et al., 2015). These initiatives are in accordance to the 2030 Agenda for the Sustainable Development Goals (SDGs), as tools for regional and local planning contexts to contribute to the implementation of public policies based on the priority objectives of governments and local actors (UN, 2015).

The local use of greywater in agriculture as well as other new sanitation practices bring up new paradigms and requires the human perception change to the reuse of waste (Hu et al., 2016; Brands, 2014; Werner et al., 2009; Bracken et al., 2007; Langergraber et al., 2005). The implementation of these new sanitation procedures could be a challenge, and to know the people acceptance of the greywater reuse in agriculture is crucial to guide public policies and the decision-making by public agents (Poortvliet et al., 2018; Brands, 2014). In this scenario, researches dedicated to social acceptance and perceptions of the risks and benefits of greywater reuse practices are needed (Simha et al., 2018).

Studies from different parts of the world aiming to evaluate the public perception and acceptation for the greywater reuse have been developed, looking for provide indicators for the establishment of local development policies (Quezada et al., 2016). Even there is a predominance of perception evaluations using a general public, it would be more interesting and effective to know the perception of specific groups concerning to the wastewater reuse (Poortvliet et al., 2018). Then, different research strategies have been adopted focusing in groups as key social actors, climatic region and water availability (Oteng-Peprah et al., 2018). An interesting group are the professionals that work directly with rural communities, such as technicians of rural assistance, because they are potential disseminators of sanitation practices in these places.

This study addresses the following research question: What is the acceptance for the greywater reuse in agriculture in the Brazilian state of Minas Gerais? This study aims to evaluate the acceptance and perception of the risks and benefits of greywater reuse as an alternative water resource in agriculture in Brazil. A survey was carried out with rural technical assistance professionals in Minas Gerais to answer the research questions. The research chose to evaluate the acceptance and perception of the use of greywater in agriculture with rural assistance technicians because this group aims to promote sustainable development through technical assistance in the field, to improve the quality of rural life (EMATER-MG, 2021). The opinion of these professionals is relevant because it can contribute to the actions of farmers since, most of the time, they are the technical opinion that supports them in making decisions. In addition, understanding the position of these professionals is an initial step to evaluate the effectiveness of any public policies and even the need to reorient them to achieve the intended goals.

In this study, we considered the Attitude and the Perceived Behavioral Control (PBC) to investigate the acceptance and perception of the risks and benefits of the rural technical assistance professionals to use greywater in agriculture. The attitude is a favorable or unfavorable feeling associated with performing a particular behavior (Ajzen, 1991). It means that a person will have a favorable attitude toward performing a particular behavior if they believe it will be positive and vice-versa. The PBC refers to the person's perception of capacity or difficulty to perform the behavior (Ajzen, 2002). It is the person's understanding if they believe they have the tools or resources necessary to perform the behavior. Based on this, we hypothesize that the acceptance to perform the greywater use in agriculture (behavior) will be identified by those professionals who demonstrate a positive attitude about greywater reuse and who believes that the practice is possible to be performed due to its risks and benefits.

2. Methodology

This study was previously approved by the Committee for Ethics in Research with Humans from the Federal University of Viçosa – MG (CAAE: 36853620.0.0000.5153).

2.1. Sampling procedures

The population surveyed considers professionals from the Technical Assistance and Rural Extension Company of the State of Minas Gerais (Emater-MG, in Portuguese acronyms), a public institution involved in promoting agricultural practices, water management, and sanitation in rural areas. This company staff was considered an interesting public to evaluate the acceptance and perception of greywater use in agriculture because they are opinion-makers with farmers. The technical staff is formed mainly by agronomists, veterinarians, and zootechnics. The state of Minas Gerais is the fourth largest state in Brazil (586,522 km^2) and the second most populated (21,411,923 inhabitants) (IBGE, 2021).

All professionals were contacted by institutional E-mails facilitated by the Emater-MG administration when the research goals were previously presented. The data collection was carried out through a structured questionnaire in an online format, designed using Google Forms (TM). Participants were invited to answer the questions from November to December 2020. In total, 1243 professionals were invited to participate in this study voluntarily. The sampling was restricted to the Emater-MG actuation regions in the 12 mesoregions of the Minas Gerais State in the Southeast of Brazil (Fig. 2).

2.2. Questionnaire form

Before answering the questionnaire (Anexo 1), the participants were invited to accept the Terms of Informed Consent (TIC), a condition required to get access to the form. The questionnaire consisted of three consecutive sections: Participant Information (S1), Acceptance and Perception towards Greywater and its Use (S2), and New Ecological Paradigm (NEP) scale (S3).

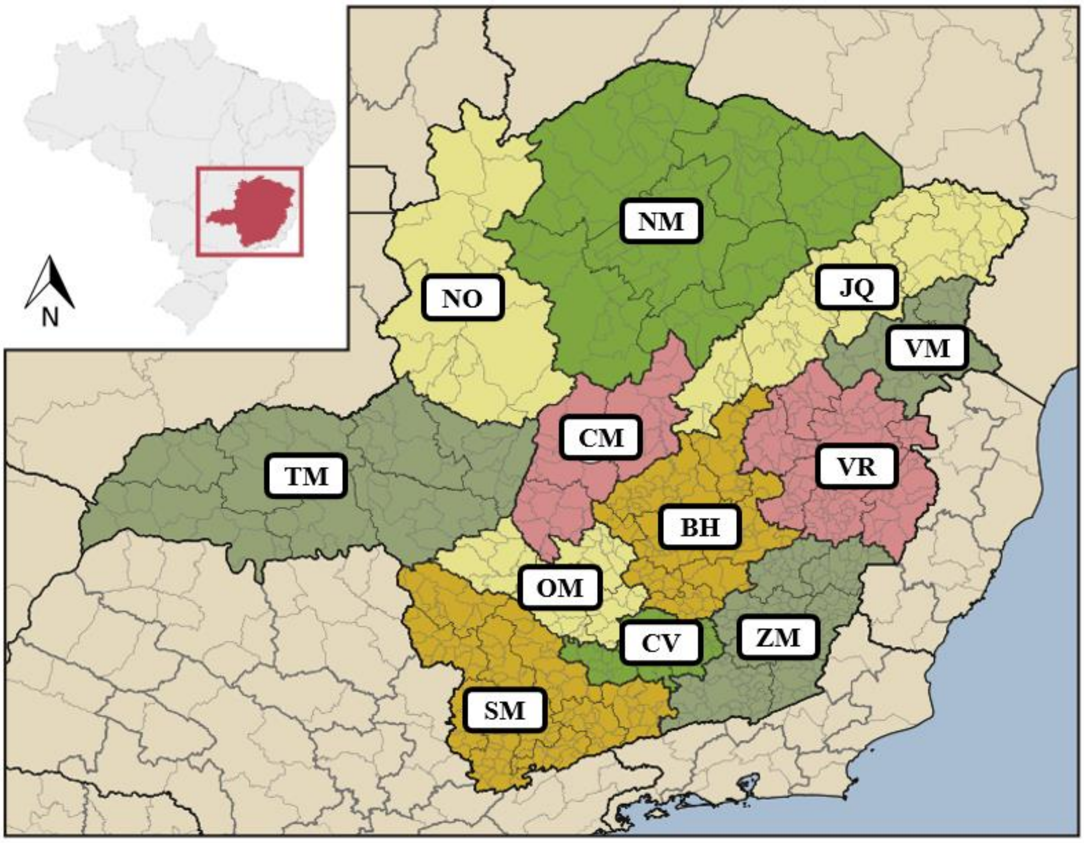


Figure 2: Mesoregions of the Minas Gerais State, Brazil: (CV) Campo das Vertentes, (CM) Central Mineira, (JQ) Jequitinhonha, (BH) Metropolitana de Belo Horizonte, (NO) Noroeste de Minas, (NM) Norte de Minas, (OM) Oeste de Minas, (SM) Sul e Sudoeste de Minas, (TM) Triângulo Mineiro e Alto Paranaíba, (VM) Vale do Mucuri, (VR) Vale do Rio Doce, (ZM) Zona da Mata (IBGE, 2017).

The "Participant Information" section (S1) requested demographic information, including gender, age, and professional actuation mesoregion. Participants were asked for single responses to multiple-choice questions.

The “Acceptance and Perception towards Greywater and its Reuse” section (S2) was divided into subsections to evaluate the perception about “water scarcity” (3 questions), “perceived advantages” (4 questions), “perceived risks” (6 questions), and “attitudes associated” (8 questions), all of them related to the use of greywater as a resource (Domènecha et al., 2010; Busgang et al., 2015; Bakare et al., 2016).

The “New Ecological Paradigm scale” (NEP) section (S3), proposed by Dunlap, aimed to assess the personal environmental values and beliefs (15 statements) (Poortvliet et al., 2018; Simha et al., 2018; Dunlap et al., 2000).

The two last sections (S2 and S3) were measured using a 6-point Likert scale, requiring the participants to react to affirmatives considering their level of agreement (entirely disagree (1), disagree (2), slightly disagree (3), slightly agree (4), agree (5), and entirely agree (6) (Dunlap et al., 2000).

2.3. New Ecological Paradigm

The NEP analysis considered the response for each statement of the section. For each NEP statement we recorded the percentage of interviewers who declare their level of agreement (from entirely disagree (1) to entirely agree (6)). The 15 statements of the NEP scale are divided into five hypothetical facets of ecological worldview: 1st facet - Limits to growth (statements 1, 6, and 11), 2nd facet - Anti-anthropocentrism (statements 2, 7, and 12), 3rd facet - Balance of nature (statements 3, 8, and 13), 4th facet - Anti-exemptionalism (statements 4, 9, and 14), 5th facet - Eco-crisis (statements 5, 10, and 15) (Dunlap et al., 2000). The score of each facet ranged from 3 (anthropocentric vision) to 18 (pro-environmental vision), with a 10.5 neutral score (de Souza et al., 2021). We analyze the mean NEP score for both each statement and each facet, and use this value to classify the positioning in the class approach: anthropocentric vision (< 3.5) and environmental vision (≥ 3.5). The General NEP score can vary from 15 (anthropocentric vision) to 90 (environmental vision), where 52.5 is neutral score (Dunlap et al., 2000).

2.4. Attitude and Perceived Behavioral Control

For the attitude, three aspects were considered to evaluate the respondents’ attitude towards the use of greywater: (As1) perception of greywater as an alternative water resource (questions 8 to 11); (As2) willingness to carry out the greywater use practice (questions 18 to 20); and (As3) willingness to consume food grown with greywater (questions 21 and 22). The individual attitude score for each aspect (IAsSc) was estimated using Equation 1, where r is the response (between 1 to 6) for each question. Using this procedure, the three aspects were considered with equal importance (even with a different number of questions (Nq)) to estimate the individual attitude score (IatSc) concerning the use of greywater in agriculture (Equation 2). The overall attitude score was calculated with Equation 3, considering the number of participants (N). Aiming to evaluate the attitude concerning each aspect (As), we use the overall aspect score (Equation 4).

$$\text{Individual aspect score (IasSc)} = \left[\frac{1}{N_q}\sum r_i\right] \quad \text{(Equation 1)}$$

$$\text{Individual attitude score (IatSc)} = \frac{\sum IAsSc_i}{3} \quad \text{(Equation 2)}$$

$$\text{Overall attitude score } \frac{\sum IAtSc_i}{N} \quad \text{(Equation 3)}$$

$$\text{Overall aspect score} = \frac{\sum IAsSc_i}{N} \quad \text{(Equation 4)}$$

The Perceived Behavioral Control (PBC) was evaluated after asking the technicians concerning human health risks to using greywater as a water resource in agriculture (questions 12 and 13). In addition, questions 14 to 17 ask about the viability of performing the practice more safely. The PBC score is estimated by the mean of the grades recorded in the questions from Q12 to Q17.

2.5. Data and Statistical analysis

The Kruskal-Wallis Test (Kruskal and Wallis, 1952) was used to evaluate the influence of demographic variables on the participants' perceptions about greywater reuse and environmental attitudes (NEP). The Dunn Test was performed to evaluate the influence of the different groups (age and mesoregions) on each demographic variable by multiple comparisons per question of the questionnaire. The differentiation among demographic variables groups (gender, age, and mesoregions) considered a 0.05 significance level.

Individual responses from the professionals from 1 to 6 to the NEP statements were assessed to the internal consistency by the coefficient of Cronbach’s Alpha (α)

(Cronbach, 1951). The α coefficient ($0 < \alpha < 1$) was calculated to check whether the research participants were internally consistent in their stated responses on the NEP scale (Dunlap et al., 2000). In the NEP scale evaluation, the Factor Analysis with Varimax rotation and the Kaiser, Meyer, Olkin (KMO) test were used to estimate sampling adequacy.

The average of the overall rating in the 6-point Likert scale ($1 \le \mu \le 6$) was used to analyze the respondents' environmental perspectives. We consider positive perceptions to use of greywater (S2) and pro-environmental attitudes (S3) when $\mu > 3.5$, and negative perceptions to greywater use and pro-anthropocentrism attitudes when $\mu < 3.5$.

All statistical analyses were carried out using R (R Core Team, 2020, Version 4.0.2).

3. Results

We obtained 300 responses to the questionnaire, representing 24,1% of the study population (N = 1243), with 95% confidence level, the margin of error was estimated to be <5%.

3.1. New ecological paradigm

The NEP mean score of 65.80 ± 10.27 indicates that respondents, in general, tend to be more pro-environment (Table 1). The Cronbach's Alpha (α) ($0 < \alpha < 1$) varied between 0.75 and 0.80, indicating as acceptable the internal consistency in the NEP scale (Cronbach, 1951). The KMO test was estimated equal to 0.81, indicating optimal sampling adequacy to the factor analysis. The comparison between the facets showed NEP score with low variance and a pro-environmental tendency. In a scale from 3 to 18, the NEP scores varied from 12.56 to 13.87 to Limits to growth (mean of 12.96 ± 2.75), anti-anthropocentrism (mean of 13.25 ± 2.99), balance of nature (mean of 13.87 ± 2.74), anti-exemptionalism (mean of 12.56 ± 2.55), and eco-crisis (mean of 13.15 ± 3.32).

Table 1 – The statements and facets of the New Ecological Paradigm (NEP) scale, NEP mean and standard deviation, position, median and Cronbach's Alpha coefficient (α).

NEP scale [1]	Mean NEP	SD	Position	Median	Cronbach's Alpha (α)
General score	65.80	10.27	+	66.00	0.78
1º facet - Limits to growth	12.96	2.75		13.00	
1. We are approaching the limit of the number of people the Earth can support	3.79	1.58	+	4.00	0.77
6. The Earth has plenty of natural resources if we just learn how to develop them	5.11	1.13	+	5.00	0.80
11. The Earth is like a spaceship with very limited room and resources	4.06	1.53	+	4.00	0.77
2º facet - Anti-anthropocentrism	13.25	2.99	+	13.00	
2. Humans have the right to modify the natural environment to suit their needs	3.86	1.52	+	4.00	0.77
7. Plants and animals have as much right as humans to exist	5.22	1.17	+	6.00	0.77
12. Humans were meant to rule over the rest of nature	4.17	1.55	+	5.00	0.77
3º facet - Balance of nature	13.87	2.74	+	14.00	
3. When humans interfere with nature it often produces disastrous consequences	4.45	1.38	+	5.00	0.76
8. The balance of nature is strong enough to cope with the impacts of modern industrial nations	4.65	1.42	+	5.00	0.77
13. The balance of nature is very delicate and easily upset	4.77	1.19	+	5.00	0.76

NEP scale (1)	Mean NEP	SD	Position	Median	Cronbach's Alpha (α)
4º facet - Anti-exemptionalism	12.56	2.55	+	12.00	
4. Human ingenuity will ensure that we do not make the Earth unlivable	3.41	1.53	-	3.00	0.78
9. Despite our special abilities, humans are still subject to the laws of nature	5.36	0.77	+	6.00	0.78
14. Humans will eventually learn enough about how nature works to be able to control it	3.79	1.42	+	4.00	0.78
5º facet - Eco-crisis	13.15	3.32	+	13.00	
5. Humans are seriously abusing the environment	4.92	1.21	+	5.00	0.75
10. The so-called "ecological crisis" facing humankind has been greatly exaggerated	3.79	1.54	+	4.00	0.77
15. If things continue on their present course, we will soon experience a major ecological catastrophe	4.44	1.46	+	5.00	0.75

Concordance levels: Strongly Disagree (1), Disagree (2), Partially Disagree (3), Partially Agree (4), Agree (5), and Strongly Agree (6).
General NEP score: 15 (more anthropocentric vision) to 90 (more environmental vision), and 52.5 as a neutral score.
Facets score: 3 (anthropocentric vision) to 18 (pro-environmental vision), and 10.5 as a neutral score.
(1) NEP scale with the general score, the five facets and each statement.
SD= standard deviation

3.2. Attitude towards the use of greywater

The demographic profile of respondents who responded to our questionnaire form is composed of men (84.3%), aged over 40 years (89.0%), from all 12 mesoregions of Minas Gerais, and have a pro-environmental vision (85.3%) (Table 2).

The overall attitude score concerning the use of greywater in agriculture was 4.39 ± 0.93. Considering this average is > 3.5, the result suggests that, in general, there is a positive attitude of the surveyed professionals to the use of greywater in agriculture (Table 2). The general attitude concerning the use of greywater in agriculture was not affected by age, mesoregion-based, and environmental position (NEP) of professionals. Just gender influenced this attitude, with women (attitude score: 4,69, table 2) presenting more positive attitude than men (attitude score: 4,33, table 2) to the agriculture use of greywater.

The analysis of the overall aspect scores (As1, As2, and As3) related to the attitude to using greywater revealed that most professionals present a positive attitude for all aspects evaluated, both for all responders and the demographic categories (Table 2). When asked about the possibility of using greywater as an alternative water resource (As1) and the willingness to perform the practice of this use (As2), more than 80% of interviewers exhibit a very positive attitude (81.3% to As1 and 87.7% to As2). This performance is reduced when asked about the willingness to consume food grown with greywater (As3). In this case, the overall aspect score was 59.3% for the all interviewed group.

The Kruskal-Wallis test was applied to assess if there are differences inside the demographic categories to the perceptions of greywater use (Table 3). The environmental position (NEP scale) of professionals is not affected by gender and age but is influenced by where they are based (Table 2). This can indicate that their surroundings influence the professional perception.

Gender, age and professional mesoregions influenced some agreement of some of the questions about water scarcity (Q5 to Q7), perceived advantages (Q8 to Q11), perceived risks (Q12 to Q17), and acceptance/attitudes (Q19 to Q25) related to the use of greywater in agriculture.

Questions not affected by gender, age, mesoregion and environmental position (NEP) were Q10 (perceived advantages); Q12, Q13, Q14, Q15, and Q16 (perceived risks), and Q21 and Q22 (attitudes associated).

Table 2 – Professionals interviewed in function of gender, age, their mesoregion-based, and their environmental attitude with their general attitude score, scores by aspects (As1, As2 and As3), NEP scores, and PBC scores.

Demographic variable	n	Attitude Score			Aspects (%) [(2)]			NEP		PBC	
		Mean[(3)]	SD	Position[(1)]	As1	As2	As3	Mean[(4)]	SD	Mean[(3)]	SD
General Attitude	300	4.39	0.93	+	81.3	87.7	59.3	4.17	0.70	3.83	0.60
Gender											
Man	253	4.33 B	0.96	+	79.4	84.2	59.3	4.14 A	0.71	3.81 A	0.60
Woman	47	4.69 A	0.71	+	91.5	93.6	59.6	4.33 A	0.59	3.95 A	0.59
Age											
31-40	33	4.46 A	0.92	+	78.8	84.8	48.5	3.90 A	0.74	3.86 A	0.67
41-50	120	4.52 A	0.81	+	88.3	90.8	67.5	4.23 A	0.73	3.84 A	0.55
51+	147	4.26 A	1.01	+	76.2	81.6	55.1	4.19 A	0.65	3.82 A	0.62
Mesoregion											
Noroeste de Minas (NO)	6	4.76 A	0.81	+	100.0	100.0	50.0	4.41 AB	0.33	4.22 A	0.46
Norte de Minas (NM)	28	4.50 A	0.93	+	82.1	89.3	50.0	4.24 AB	0.71	3.84 A	0.57
Jequitinhonha (JQ)	32	4.54 A	0.98	+	87.5	87.5	65.6	3.84 A	0.67	3.84 A	0.57
Vale do Mucuri (VM)	15	4.08 A	0.87	+	80.0	80.0	40.0	4.27 AB	0.49	3.77 A	0.51
Triângulo Mineiro (TM)	21	4.33 A	0.83	+	81.0	76.2	66.7	3.87 AB	0.73	3.85 A	0.57
Central Mineira (CM)	30	4.37 A	1.02	+	80.0	83.3	63.3	4.21 AB	0.61	3.84 A	0.53
Metropolitana de Belo Horizonte (BH)	14	4.56 A	0.92	+	85.7	92.9	50.0	4.16 AB	0.46	3.74 A	0.52
Vale do Rio Doce (VR)	27	4.36 A	0.78	+	77.8	92.6	55.6	4.24 AB	0.77	3.62 A	0.58
Oeste de Minas (OM)	8	4.19 A	1.01	+	62.5	87.5	37.5	4.02 AB	1.13	4.23 A	0.53
Sul e Sudoeste de Minas (SM)	41	4.32 A	0.93	+	78.0	87.8	61.0	4.47 B	0.71	3.80 A	0.69
Campo das Vertentes (CV)	14	4.62 A	1.09	+	85.7	85.7	78.6	3.75 AB	0.76	3.88 A	0.81
Zona da Mata (ZM)	63	4.33 A	0.96	+	81.0	82.5	63.5	4.24 AB	0.63	3.86 A	0.62

Demographic variable	n	Attitude Score			Aspects (%) [2]			NEP		PBC	
		Mean[3]	SD	Position[1]	As1	As2	As3	Mean[4]	SD	Mean[3]	SD
Environmental attitude											
Pro-environmental vision	256	4.43 A	0.86	+	84.8	87.1	59.4	4.37 A	0.42	3.87 A	0.60
Anthropocentric vision	44	4.12 A	1.22	+	61.4	77.3	59.1	3.04 A	0.53	3.63 B	0.52

[1] Professionals' attitude to the use of greywater in agriculture: positive favorable (+) and negative position (-).

[2] Percentage of interviewers who demonstrate a favorable position (> 3.5) to the use of greywater in agriculture reuse considering the following aspects: perception of greywater as an alternative water resource (As1); willingness to carry out the greywater use practice (As2); and willingness to consume food grown with greywater (As3)

[3] Kruskal-Wallis Test to define statistical differences in the Attitude and PBC in function of demographic variables.

[4] Dunn's Test to define statistical differences in the NEP scale in function of demographic variables.

SD= standard deviation

There was no difference between gender and age concerning the questions related to water scarcity (Table 3). When is considered the mesoregion where professionals are based, differences are observed and are related to the water available dissimilarity observed in this State. Professionals from Norte de Minas (Q5, Q6 and Q7) and Jequitinhonha (Q6 and Q7) agreed more regarding the statements presented by the questions related to water scarcity than ones from other mesoregions (Table 4).

For the questions about perceived advantages and risks of using greywater reuse, woman perceptions are more favorable to this use (Table 3). There are no differences in perceived advantages and risks to different groups or age and mesoregion.

Questions related to the attitudes/attitudes revealed the influence of gender, age and mesoregion in some questions, but without any standardization (Table 3). Woman professionals exhibit more acceptance to use greywater in agriculture (Q18, mean: 5,15), and this wastewater use is a potential resource to small farmers (Q24, mean 4,34) than men professionals (mean of 4,69 and 3,85, respectively).

The perception of the feeling safe to apply greywater in food gardens (Q20) exhibits differences just when age groups were considered (Table 3). According to Dunn's test, the oldest group (+50) (mean 3.46) is less favorable to this statement than professionals with 41 to 50 years old (mean 3.95). The youngest group (< 40) (mean 3,79) stand between those two other age groups. The origin mesoregions of professionals influenced their acceptance to apply greywater in flower gardens and trees (Q19) and the perception that greywater use is more appropriated in the dry season (Q23), but just for one pair of comparison between two mesoregions in each question. Most parts of mesoregions agree to present the same perception level about both statements.

When asked if greywater use in agriculture would be a promising practice for family farmers in the region where professionals are based (Q24), most professionals (65.0%) believe that greywater use is a promissory practice to the family farmers. This finding considers the professional percentage whom grade > 3,5 on Q24. We find a correlation between the individual score on Q24 and each final attitude score of the professional ($r = 0.56$, $p<0.05$). This correlation coefficient reflects a moderate relationship between the two variables. Therefore, professionals who exhibit a more favorable attitude to the greywater use in agriculture are related to them believe this practice is promissory to the family farmers.

When asked if public policies would be interesting to expand the greywater use where they are based (Q25), no differences were verified to gender, age groups and origin mesoregion (Table 3). However, in general, 81.7% of the respondents agree with this statement (Table 5), highlighting the Noroeste de Minas (NO) and Norte de Minas (NM) mesoregions with more acceptance. This agreement considered those answers with the grade ≥ 3,5. The supplementary data available from the Brazilian Institute of Geography and Statistics (IBGE) shows that these two mesoregions present the lowest per capita monthly income (NO) and the highest deficit of wastewater collection in the state (NM) (IBGE, 2010).

When we compare the two classes of NEP (anthropocentric (< 3.5) or environmental (≥ 3.5)) (Table 3), we observed that professionals more pro-environmental notice more that water scarcity is recently increasing (Q7), accept more the use of greywater in agriculture (Q18) and believe more in public policies to improve the greywater use in agriculture (Q25).

3.3. Perceived behavioral control

The professionals were asked if they believed that greywater use could concern any risk to human health and if it is possible and viable to perform this agriculture practice more safely. When asked if irrigation using greywater can present risks to the population in general (Q13), 63.7% (>3.5) agree with this statement, and 47% (>3.5) believe that greywater contains pathogenic microorganisms (Q12). When asked about reducing the risks involved, 72.6% (>3.5) believe drip systems are a preventive irrigation technique (Q16) and 77.0% (>3.5) that it is viable to perform the previous local treatment of this wastewater (Q17). Therefore, the perceived behavioral control of most professionals is that the risks involved in the use of greywater in agriculture could be mitigated.

The perceived behavioral control verified in this study was not influenced by demographic variables as gender, age and mesoregion-based. The NEP classes affect the PBC, in this case, the PBC of professionals with environmental vision (≥ 3,5) is bigger than those from anthropocentric vision ones (< 3,5).

Table 3: Results of p-values from the Kruskal-Wallis test to define statistical differences in different variables in function of demographic variables (gender, age, mesoregion-based, and environmental attitude (NEP classes)).

Demographic variable	**Water scarcity**			**Perceived advantages**			**Perceived risks**	**Acceptation/Attitudes**					
	Q5	Q6	Q7	Q8	Q9	Q11	Q17	Q18	Q19	Q20	Q23	Q24	Q25
Gender	0.261	0.605	0.226	0.001*	0.002*	0.028*	0.043*	0.036*	0.656	0.149	0.375	0.043*	0.101
Age	0.776	0.982	0.975	0.479	0.910	0.757	0.577	0.798	0.073	0.042*	0.787	0.551	0.962
Mesoregion	0.001*	0.000*	0.003*	0.087	0.683	0.547	0.415	0.186	0.005*	0.640	0.020*	0.166	0.144
NEP classes	0.067	0.082	0.019*	0.094	0.119	0.093	0.033*	0.035*	0.079	0.607	0.521	0.471	0.016*

* $p<0.05$

NEP Classes: two classes proposed: anthropocentric vision (< 3,5) and environmental vision (≥ 3,5).

Differences evaluate according to the statements organized to diagnose professional perception of how the use of greywater in agriculture is related to the "water scarcity" (Q5, Q6 and Q7), "perceived advantages" (Q8, Q9 and Q11), "perceived risks" (Q17), and "attitudes associated" (Q18, 19, 20, 23, 24 and 25).

Table 4: Divergent results of mean score obtained from professionals mesoregion-based to the questions (Q5, Q6, Q7) related to the water scarcity

Statements	**Correlations**				
	Mesoregion	**Score question mean**	**Mesoregion**	**Score question mean**	**p-value** [1]
"My region has experienced water rationing for the past 10 years" (Q5)	Norte de Minas	5.46	Metropolitana de Belo Horizonte	3.79	0.0493
			Noroeste de Minas	2.50	0.0197
			Sul e Sudoeste de Minas	4.12	0.0162
			Zona da Mata Mineira	4.13	0.0021
"In my region water scarcity is common at least once a year" (Q6)	Norte de Minas	5.21	Campo das Vertentes	3.29	0.0460
			Central Mineira	3.23	0.0006
			Sul e Sudoeste de Minas	2.98	0.0000
			Triangulo Mineiro e Alto Paranaíba	3.14	0.0015
			Zona da Mata Mineira	3.10	0.0000
	Jequitinhonha	4.88	Central Mineira	3.23	0.0079
			Sul e Sudoeste de Minas	2.98	0.0001
			Triangulo Mineiro e Alto Paranaíba	3.14	0.0151
			Zona da Mata Mineira	3.10	0.0000
"In my region the scarcity of water is getting worse with time" (Q7)	Norte de Minas	5.18	Zona da Mata Mineira	3.90	0.0300
	Jequitinhonha	5.22			0.0026

[1] Significates p-values according to the Dunn's Test

Score scale from 1 to 6: entirely disagree (1), disagree (2), slightly disagree (3), slightly agree (4), agree (5), and entirely agree (6).

Table 5: Mesoregions of Minas Gerais State, Brazil, indicating the percentage of rural technical assistance professionals that agreed (Q25>3.5) in the development public policies to improve the use of greywater in the region where they are based (Question 25), the percentage of deficits of access to water supply and sewage collection, and the per capita monthly income (R$).

Mesoregion	Public Policies (% that agree)	Water Supply Deficits (%)*	Wastewater Collection Deficits (%)*	Monthly income*** (R$/person)*
General**	81.7	13.9	24.7	877
Noroeste de Minas	100.0	21.6	42.0	500
Norte de Minas	96.4	21.3	67.0	678
Jequitinhonha	81.3	31.5	53.9	428
Vale do Mucuri	86.7	27.3	41.3	530
Triângulo Mineiro/Alto Paranaíba	71.4	9.9	12.9	954
Central Mineira	73.3	13.6	33.5	714
Metropolitana de Belo Horizonte	78.6	5.1	16.1	1163
Vale do Rio Doce	77.8	22.9	27.0	643
Oeste de Minas	75.0	10.9	16.4	801
Sul e Sudoeste de Minas	73.2	18.0	20.2	811
Campo das Vertentes	85.7	14.5	23.2	780
Zona da Mata	87.3	19.3	25.2	801

*Supplementary data. Source: IBGE, (2010), adapted from Rodrigues et al., 2019.

**General average for the state of Minas Gerais.

*** Considering that in 2010 the minimum salary in Brazil was 510 reais and 1 dollar was equivalent to 1,7603 reais (Ipeadata, 2021).

4. Discussion

The acceptance and perception of risks and benefits of rural assistance technicians for the use of greywater as an alternative water resource in agriculture were investigated in this study. Our research aims to contribute to the discussions related to the reuse of water in agriculture and provide inputs for developing public policies for the reuse of effluents.

The survey was carried out with the expressive participation of 24.1% of the state technical assistance company staff, which ensuring more excellent reliability in the results since it provides a margin of error of less than 5%.

4.1. Acceptance and perception for greywater use in agriculture

In general, the rural technicians interviewed presented a positive attitude towards using greywater in agriculture (mean attitude score of 4.39 ± 0.93), much higher than the minimum required (3.5) for a positive acceptance towards the practice.

The willingness of these technicians to consume food grown with greywater (As3) was the least positive aspect compared to the other aspects (As1, As2) considered to interpret the attitude towards the reuse of this water. In this case, the willingness to consume food grown with reused water indicates a factor that may reduce acceptance of the practice. This behavior can be considered natural, given that greywater, like other wastewaters, can have harmful impacts on human health (Busgang et al., 2015; Shi et al., 2018).

The World Health Organization (WHO) suggests that greywater could be used in vegetable irrigation for raw consumption if quality control techniques are adopted to reduce pathogen contamination (WHO, 2006). Radingoana et al. (2020) show that the level of public acceptance for greywater use in food production is mainly conditioned on the type of crop to be consumed uncooked, given the previously mentioned concern for the health safety of the practice. This same finding can be highlighted in our study since there was greater acceptance of the greywater use in tree and garden irrigation (Q19) than in vegetable gardens (Q20). The result indicates great potential for the use of greywater as an alternative water resource for irrigation of non-food crops or crops that depend on cooking. This same public understanding of greywater use in garden irrigation is perceived in different places, such as in Oman (Jamrah et al., 2007) and

Bangkok (Jiawkok et al., 2013), where, respectively, 76 and 74% of the interviewed population favored this use.

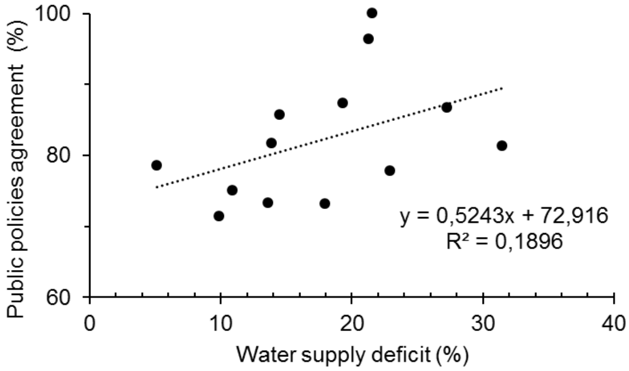
In general, the rural assistance technicians interviewed presented a more pro-environmental position (mean NEP score of 4.17 ± 0.7). However, this environmental position did not influence the general attitude of the interviewees towards the acceptance of greywater use in agriculture. This shows that environmental position, as defined by the NEP scale, is not a decisive guarantee for a final attitude towards the use of greywater in agriculture for the studied public. This same situation was observed when a specific group from a India University was evaluated to assess the intention to use ecological sanitation solutions for agricultural purposes (Simha et al., 2018). However, when another study was carried out with a more general audience, environmental position influenced the intention to use new sanitation systems (Poortvliet et al., 2018). This contrast suggests that environmental position when evaluating the positioning of more diverse groups regarding the use of new sanitation alternatives may be more determinant than when more homogeneous groups are considered. More homogeneous groups tend to be less diverse and have more common perceptions about environmental issues.

In different studies, demographic variables are interpreted as indicators to predict a population´s acceptance to water reuse (Radingoana et al., 2020). In this study, gender was a strong indicator of attitude, acceptance, and perceptions of advantages and risks. Women were shown to have the most favorable acceptance and the most positive perception of the environmental and economic benefits of greywater use in irrigation and the increased availability of potable water. Previous studies found the same situation when assessing the attitude and perceived advantages for greywater reuse in a low-cost housing development in South Africa (Bakare et al., 2016).

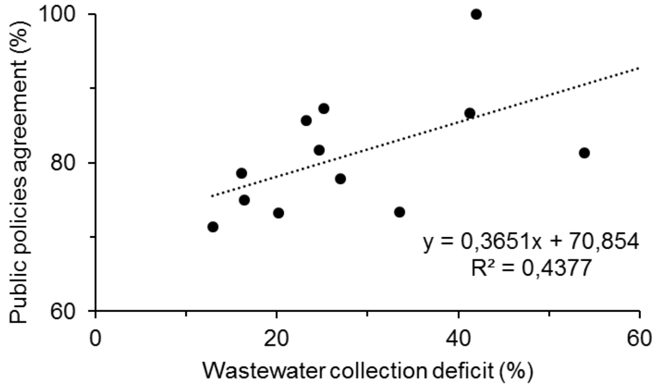
The demographic variable age did not prove to be a strong indicator of the behavior of this population. It only proved to be significant in relation to the respondents´ comfort in applying greywater in vegetable gardens. We identified that the intermediate age group (41 to 50 years) were more favorable when compared to the younger (<40 years) and the older (> 51 years). This is interesting as different results have been reported in previous studies, where it was observed that the most favorable acceptance of water reuse is correlated to younger audiences (Radingoana, et al. 2020). This was the case in the study by Bakare et al. (2016), who evidenced decreasing willingness to reuse greywater with increasing age groups.

Our study indicated a relationship between the demographic variable mesoregion and water scarcity and attitude towards the use of greywater in agriculture. The positioning of respondents to the statements related to water scarcity (Q5, 6, 7 and 23) indicated a significant difference in attitudes in different mesoregions. These differences were related to water availability in this state. The mesoregions Norte de Minas and Jequitinhonha, which most agreed with the statements, are included in the SUDENE (Superintendence for the Development of the Northeast) area, a Brazilian agency created to address chronic droughts and the semi-arid climate. Naturally, there is a predominance of research with populations living under increased water stress indicating higher acceptance for alternative uses of this resource (Oteng-Peprah et al., 2018). This finding indicates in our study a more favorable attitude towards the use of greywater in agriculture by technicians working in places that have historically lived with drought for more time.

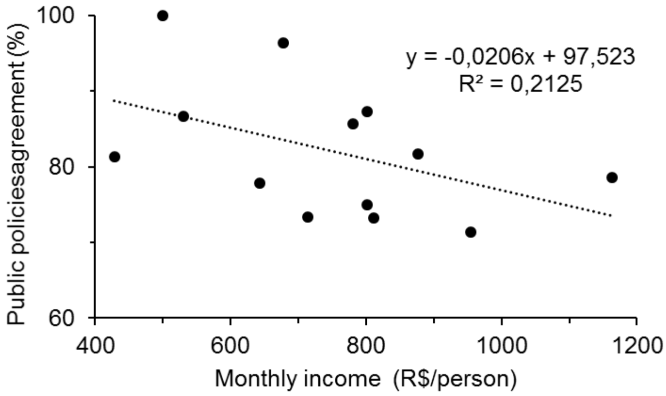
A similar result can be highlighted with the agreement to develop a public policy to expand greywater reuse. The climatic and socioeconomic characteristics of local contexts are determinants of users' attitudes. In our study, it was evident that the respondents from the mesoregions with the most significant deficit in water supply, wastewater collection, and lower monthly average income are the ones that most approve of developing a public policy for greywater reuse (Figure 3).



(A)



(B)



(C)

Figure 3: Correlation analysis illustrating the relationship between respondents' agreement with public policies addressed to the greywater reuse and (A) the water supply deficit, (B) the wastewater collection, and (C) the monthly income in different mesoregions of Minas Gerais.

As presented and discussed in the attitude, the interviewees presented less acceptance for consuming food grown with greywater use (Asp3). We identified that this behavior is in agreement with perceived behavioral control (PBC). The perception of possible health risks from greywater indicates the repugnance of food consumption that may interfere with the user's intention to perform the practice (Amaris et al., 2020). Therefore, it is evident that the quality of greywater is a determining factor in the attitude towards greywater use in agriculture (Newcomer et al., 2017). Our results highlight that most professionals believe that greywater use in agriculture is achievable with the adoption of local treatment and irrigation techniques for the risk mitigation (example, drip irrigation, as indicated by WHO (2006)). However, consumers may still experience a lack of quality control (Simha et al., 2018). Our study evidence that professionals have a higher acceptance of consuming food produced at home (Q22) than produced by other farmers (Q21). In addition to these issues, previous studies have shown that the source of greywater is also determinant in acceptance of greywater use in food cultivation, and users reported high acceptance of the practice with bath water (Newcomer et al., 2017). In Brazil, 90% of the family farmers interviewed in semi-arid regions presented a positive perception for the consumption of food grown with greywater (Cunha, 2018). These perceptions indicate that the practice of greywater reuse in agriculture is a proposal well received by farmers in these regions.

5. Conclusions

There is a positive attitude towards the use of greywater in agriculture by rural assistance technicians. They believe in the possibility of using greywater as an alternative water resource, willing to perform the practice and consuming food grown with this effluent. Despite the perception of possible health risks, these professionals believe that it is possible to perform the practice safely by adopting irrigation and treatment techniques on-site. There is more interest in greywater reuse in regions with water scarcity and a more precarious socioeconomic situation. The study highlights a positive perspective for developing public policies for water reuse, considering the rural assistance staff positioning. Future studies concerning the acceptance of greywater use in agriculture are interesting with other actors involved, such as family farmers.

Acknowledgements

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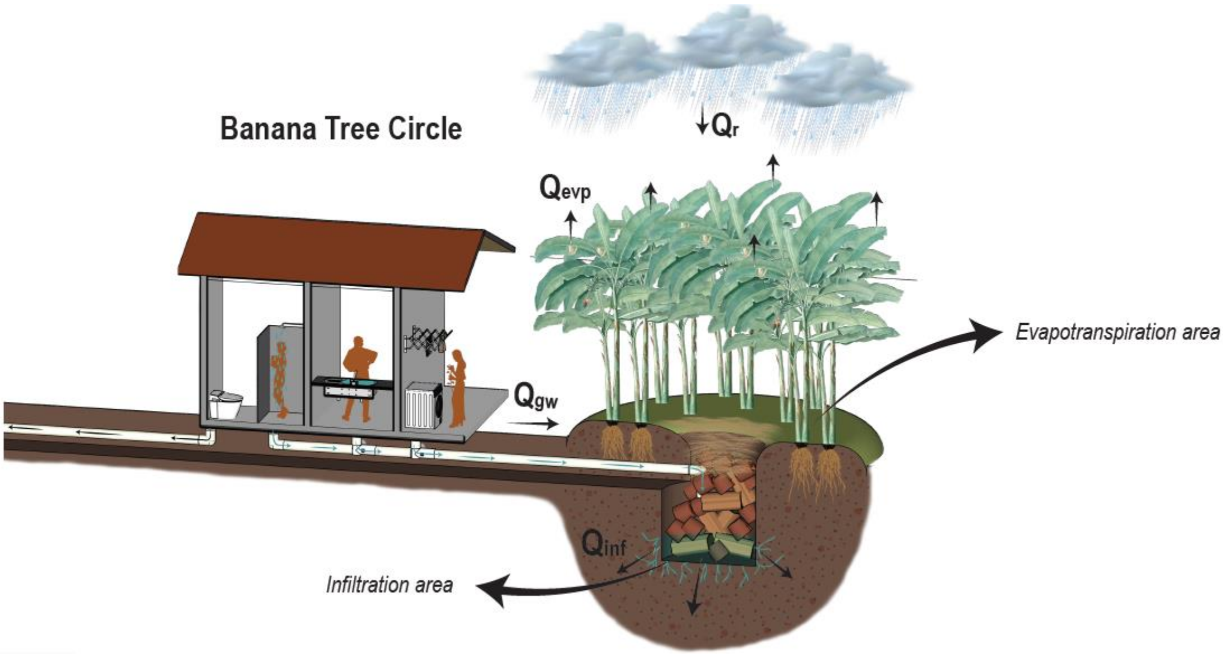
CAPÍTULO 2

Design model of Banana Tree Circle as a nature-based solution for a sustainable greywater management

ABSTRACT: The development, validation, and dissemination of simple, safe, and affordable sanitation solutions are challenges in low- and middle-income countries. A current potential solution developed by permaculture professionals is the Banana Tree Circle (BTC). BTC is a low-cost system for local greywater management, using a natural process for treatment and disposal, which provides additional resource recovery benefits. However, there are no standard design criteria for BTC that would allow for quality control of the efficiency and sustainability of this system, and little is currently known about the full-scale performance of BTC. This study aims to establish a standard design model for the BTC technology based on the concept of water balance, the flows of greywater, rain, infiltration, and evapotranspiration. A theoretical case study was performed that considered the greywater generated by a family of five people, living in a low-income context with water scarcity. The first two steps for the BTC design were to determine the areas required for infiltration and for evapotranspiration. To determine the infiltration area, a cylindrical form trench was considered, and the soil percolation rate and hydraulic loading rate were determined, and for the evapotranspiration area, the banana trees evapotranspiration rate was taken into consideration. The proposed model was applied in a case study where we considered a cylindrical infiltration trench with 0.8 m depth and 1.5 m diameter, with the greywater flow considered (110 L $(p\ d)^{-1}$) it was necessary to build two BTC units with an evapotranspiration area of 14 m^2 in each unit. The results showed the potential of this model to provide standard design criteria. This study is one contribution to the ongoing scientific validation of the sustainability and efficiency of the BTC as an innovative technology for greywater management, resource recovery, and food production in regions with water scarcity.

Keywords: Ecological sanitation, Evapotranspiration system, Wastewater reuse, Low-cost solution, Permaculture, Sustainable sanitation.

Graphical Abstract



Highlights

- A model for standard design criteria of Banana Tree Circles (BTC) is proposed
- Key parameters are greywater flow, soil percolation, and evapotranspiration rates
- Infiltration and evapotranspiration areas can be optimized using modeling
- The standard design criteria allow for better control of the performance of BTC
- Tools are provided to validate the BTC as solution for greywater management

1. Introduction

Globally, access to safe and sustainable sanitation is a challenge, especially in low- and middle-income countries (Bayu et al., 2020). Strategies for the development of technological solutions that are both economically viable, environmentally safe and operationally simple in vulnerable locations are essential to ensure the human right to sanitation (UN, 2015). According to permaculture professionals, an emerging alternative for the safe management of household wastewater is the *Banana Tree Circle* (BTC), a decentralized treatment system (Ludwig, 2015). The technology can be used for different purposes, such as composting of organic solid waste (Smith et al., 2013; Rêgo et al., 2020) and more commonly as a sustainable greywater management system (wastewater from laundry, showers, and kitchen) (Magalhães Filho et al., 2019).

The BTC is a nature-based system with superficial infiltration of greywater, based on the biochemical principles of organic matter degradation and the physical principles of filtration and evapotranspiration of water in the soil and plant systems. It consists of greywater disposal in an infiltration trench into soil filled with organic material, branches, and sticks, surrounded by banana trees (*Musa* spp.), and other plants with high evapotranspiration rates (Figure 1). Technically, it is a very simple greywater treatment system, requiring very few resources for installation, operation, and maintenance (Magalhães Filho et al., 2019). The BTC is ideal when applied in rural and peri-urban areas with available surface space. Machado et al. (2018) suggested that the evapotranspiration from plants would be sufficient to avoid possible contamination of the groundwater. Therefore, BTC has the potential to be a treatment technology with zero discharge to natural groundwater resources. In other words, it is a system that reaches maximum levels of treatment efficiency by returning water to the environment through evapotranspiration.

In addition to the economic benefits due to its simplicity, this nature-based solution integrates wastewater management practices with agriculture in line with the definition of sustainable sanitation (SuSanA, 2008) or ecological sanitation (Hu et al., 2016; Langergraber et al., 2005; Werner et al., 2009). From this perspective, greywater becomes a valuable resource for banana cultivation in places where cultivation is difficult due to water scarcity. Besides being an alternative water resource in areas facing water scarcity (Oh et al., 2018), greywater also benefits plant development because it contains macronutrients (Figueiredo et al., 2019; Siggins et al., 2016). Although the macronutrients in greywater are less pronounced when compared to urine and faeces (Brands et al., 2014), some investigations show that mixed greywater from low-income informal settlements could present high fertilizing properties, such as those found by Rodda et al. (2011) and Carden et al. (2007). The potassium in greywater accounts for 34% of its presence in domestic wastewater (Langergraber et al., 2005). Compared to freshwater, the irrigation of food crops with greywater on a small scale can be more beneficial due to the presence of these macronutrients, and contribute to increasing crop growth and production (Rodda et al., 2011). Especially in the BTC, the bananas have economic and nutritional value. They serve as a basic food in many global cultures and contain several key minerals, including potassium for human nutrition (Oyeyinka et al., 2019). Greywater is a resource that can contribute to the informal supply of domestic food and, consequently, to the local resilience of food and nutrition security.

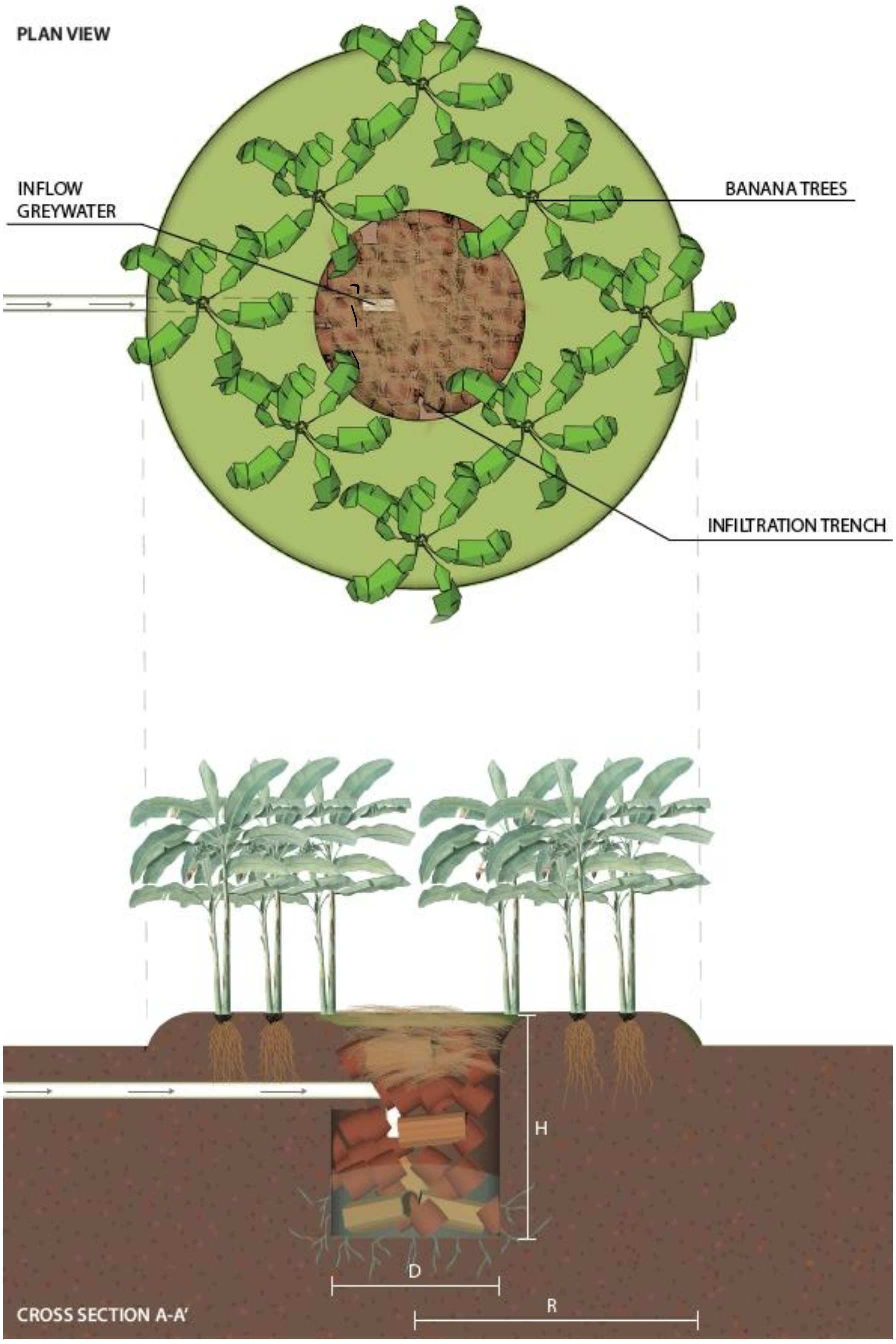


Figure 1: The Banana Tree Circle technology for domestic greywater management (where: H is the height of the trench; D is the diameter of the trench; and R is the radius of the superficial area of the BTC).

The Brazilian Ministry of Health, through the National Health Foundation (Funasa), has been promoting sustainable sanitation alternatives, including the BTC (BRASIL, 2019; FUNASA, 2018; FUNASA, 2015). Yet, standard design criteria have not been established for BTC that are based on typical engineering parameters. There are, however, many recommendations based on empirical design criteria. FUNASA, for example, recommends the following dimensions: the diameter (1.0 m) and depth (1.0 m) of the trench, and the surface area (4 m^2) (FUNASA, 2018). The Agency of Technical Assistance and Rural Extension of State of Minas Gerais recommends a surface area with 4 to 6 banana trees spaced at 0.6 m for the greywater from a household with four people (EMATER-MG, 2016; Leal, 2016). Pre-established dimensions (diameter of 2 m and depth for 0.5 – 1.0 m) and the number of banana trees (4 to 7) for the sizing of the BTC in a household also have been recommended by permaculture organizations in Australia and the United States (Buckley, 2008; Crouch, 2021).

The lack of peer-reviewed studies related to this subject, especially concerning groundwater contamination, and such factors as greywater quality, soil types, and banana evapotranspiration capacity, have limited the diffusion of this technology (Paulo et al. 2013). The potential of the use of BTC for the treatment of greywater justifies research in this area. BTC could also be analyzed as a promising technology for rural areas and in emergency and humanitarian crisis situations. Aiming to close these gaps, this study addresses two research questions: (1) how could the BTC design be standardized while optimizing physical and biochemical mechanisms, and (2) what has to be taken into account in order that BTC be considered as a viable technology in emergency and humanitarian crisis settings.

A standardized BTC design model criteria was developed to address these questions that took into account the key parameters of this technology: greywater flow, soil percolation, and evapotranspiration rates. This model has the potential to become an essential tool to validate, disseminate, and facilitate the implementation of BTC as a low-cost and sustainable solution for household greywater management and resource recovery.

2. Methodology

To develop the BTC design model, the following activities were carried out: (i) Literature review of the existing strategies for BTC design and other wastewater treatment technologies. (ii) Definition of the model design approach. (iii) Selection of the most relevant parameters to be considered for the BTC design.

2.1. Background

The literature review comprised a detailed analysis of scientific articles in the Scopus, ScienceDirect, Web of Science, Google Scholar databases, and grey literature, using such keywords as "greywater" (or "grey water" or "graywater" or "gray water") combined with "banana tree circle" (or "banana circle" or "circle of banana" or "circle of banana-tree"). No publications with these terms were found in Scopus or Web of Science. In ScienceDirect, one paper was found about the use of BTC as an alternative for the final disposal of treated domestic wastewater (Paulo et al. 2013). In Google Scholar, only three documents were found: one scientific paper (Magalhães Filho et al., 2019), one book chapter (Machado et al., 2018) and one conference paper (Marshall, 1996).

Although the studies mentioned the technology as an alternative for sustainable greywater management, none of them discussed design criteria for BTC. These publications cited manuals that presented BTC construction details, particularly those published by Brazilian government institutions (FUNASA, 2018; FUNASA, 2015; EMATER-MG, 2016; Leal, 2016; São Paulo, 2012), a Non-Governmental Organization (FWS, 2021) and permaculture research institutions (Buckley, 2008; Crouch, 2021). Yet, the design and construction details of BTC were different among them.

The literature review and the synthesis of the design criteria are detailed in Table 1. The reviewed publications proposed a BTC size that would receive all the greywater from a household with four to five people. Typical design parameters for wastewater treatment units, such as the hydraulic loading rate, the crop evapotranspiration rate, the soil percolation rate, and the precipitation rate, that are relevant for this system were not considered. These results confirm that, up to now, the BTC design criteria are based only on dimensional empirical principles.

Table 1: Systematization and synthesis of current strategies for the design of the banana tree circle.

Institution	Country	Dimensions*	Construct observations	Type of plants	References
National Health Foundation (Ministry of Health)	Brazil	- Maximum diameter and depth: 1.0 m - Area: 4 m^2	- Inflow pipe (100 mm) with a minimum inclination of 2%; - Filling the trench with wood, sticks, and leaves; - The construction of another system will be necessary if the volume is higher than the receiving capacity and the type of soil.	Banana, papaya, and lily.	FUNASA (2018)
National Health Foundation (Ministry of Health)	Brazil	- Diameter: 2.0 m, - Depth: 1.0 m - Banana tree spaced at 0.6 m	-The trench filled with gravel, sticks and vegetable remains.	Banana and taioba (taro).	FUNASA (2015)
State University of Campinas	Brazil	- Diameter: 2.0 m, - Depth: 0.5 to 0.8 m	-Soil is added to the border of the trench; -In sandy soil add clay to the bottom of the trench; -The trench is filled with sticks and covered with mulch; -Plants should be planted around the trench.	Banana, papaya tree, lilium, taioba (taro) and other plants appropriate for for high humidity.	Figueiredo et al. (2018)
Technical Assistance and Rural Extension Company of the State of Minas Gerais	Brazil	- Diameter: 1.4 m, - Depth: 0.6 m; - Banana tree spaced at 0.6 m	- Inflow pipe (100 mm); - 4 to 6 banana plants; - The trench filled with wood trunks and sticks; - The construction of another system connected to the first one is necessary when the	Banana and plant species with large leaves.	Leal (2016)

			volume is higher than the receiving capacity.		
Technical Assistance and Rural Extension Company of the State of Minas Gerais	Brazil	- Diameter: 1.5 m, - Depth: 1.2 m	- Trench filled with layers of wood, sticks, leaves and haystacks.	Plant species with large leaves.	EMATER-MG (2016)
São Paulo Municipal Government	Brazil	- Diameter: 2.0 m, - Depth: 1.0 m, - Banana tree spaced at 0.6 m	- The trench should be covered with banana leaves; - Trench filled with layers of wood, sticks, leaves and haystacks.	Banana, papaya, and sweet potato.	São Paulo (2012)
NGO – food water shelter (fws)	Australia & EUA	- Diameter: 2.0 m, - Depth: 0.5 to 1.0 m.	- Are planted 4 banana trees; - The banana leaf at the bottom of the trench to increase the exposure time of the water to the plant roots.	Banana, papaya, and other plants.	FWS (2021)
Permaculture Research Institute	Australia	- Diameter: 2.0 m, - Depth: 0.5 to 1.0 m.	- 4 banana trees; - fill the trench with organic material.	Banana, pumpkins, tomatoes, taro, and ginger.	Buckley (2008)
Treeyo Permaculture	EUA	- Diameter: 2.0 m, - Depth: 0.66 m, - Border height: 0.33 m, - Border width: 0.66 m.	- 7 banana trees; - fill the trench with organic material.	Banana, cassava, lemongrass, sweet potato, and taro.	Crouch (2021)

* Dimensions are designed for a family of 4 to 5 people. For more people, some authors suggest the construction of additional BTC's to treat all greywater from the household.

2.2. Design of other nature-based treatment technologies

Wastewater treatment systems similar to the BTC were investigated in order to establish the key parameters necessary for the development of a design model. Table 2 presents some wastewater treatment systems for households that include the natural processes of soil infiltration and evapotranspiration. For each technology design criteria, typical engineering parameters related to natural processes are listed. For the infiltration trenches, the soil characteristics considered as key factors for the design criteria are those related to the soil percolation rate (min cm^{-1}) and the wastewater hydraulic loading rate (L m^{-2} d^{-1}) (Crites et al., 1998).

Table 2: Design parameters of alternatives with nature-based processes for the treatment and final disposal of domestic wastewater.

Technology	Operating principle	Design parameters	References
Infiltration trench	Subsurface infiltration of greywater into the soil in trenches. Treatment occurs through infiltration, adsorption, and biochemical reactions in the soil.	- Soil type (texture and structure); - Soil percolation rate (min cm^{-1}); - Hydraulic loading rate (L m^{-2} d^{-1}).	US EPA (1992); BRASIL (1997)
Infiltration and evapotranspiration system	Unit for the treatment and final disposal of wastewater that passes through the processes of soil infiltration and plant evapotranspiration	- Greywater flowrate (m^3 d^{-1}); - Evapotranspiration rate (mm d^{-1}); - Precipitation rate (mm d^{-1}).	US EPA (2002)
Willow bed	Wastewater disposal unit with the discharge of the whole liquid part via evapotranspiration	- Hydraulic loading rate (L m^{-2} d^{-1}); - Evapotranspiration rate (mm d^{-1}); - Precipitation rate (mm d^{-1}).	O'Hogain et al. (2011)
Evapotranspiration tank	Blackwater recovery with the aim of zero liquid discharge. The treatment happens in a filter planted with banana trees.	- Effluent flowrate (m^3 d^{-1}); - Evapotranspiration rate (mm d^{-1}); - Precipitation rate (mm d^{-1}).	Paula et al. (2019)

The willow system design, proposed for a zero discharge effluent, is based on a water balance model that takes into account the typical wastewater effluent rates, the climate conditions, and the plant characteristics (Curneen et al., 2016).

2.3. Water Balance – design approach

The water balance is a tool to understand the dynamics of how water flows in and out of a system (Headley et al., 2012; Frédette et al., 2019). For the BTC, analysis of the water balance contributes to a better understanding of its operation, whether it works as an evapotranspiration system or an infiltration/evapotranspiration system.

The benefits of BTC are zero discharge into natural superficial water resources due to evapotranspiration, as well as groundwater recharge through infiltration (Curneen et al., 2016). The system performance will depend on the location, superficial area availability, and groundwater depth. The water balance of the BTC system is given by Eq. 1.

$$Q_{gw} + Q_r = Q_{evp} + Q_{inf}, \qquad \text{(Equation 1)}$$

where Q_{gw} is the greywater flowrate ($m^3\ d^{-1}$), Q_r is the rain flowrate ($m^3\ d^{-1}$), Q_{evp} is the evapotranspiration flowrate ($m^3\ d^{-1}$), and Q_{inf} is the infiltration flowrate ($m^3\ d^{-1}$).

2.4. Theoretical case study

To simulate the proposed design strategy for the BTC, this study considered a hypothetical scenario of a household with five people, living in a developed context.

3. Results

3.1. Key parameters and variables

The BTC design criteria should include the following parameters:

- Soil percolation rate ($min\ cm^{-1}$);
- Hydraulic loading rate ($L\ m^{-2}\ d^{-1}$);
- Greywater flowrate ($m^3\ d^{-1}$);
- Crop evapotranspiration rate ($mm\ d^{-1}$);
- Precipitation rate ($mm\ d^{-1}$).

These parameters are crucial to determine the dimensions of the infiltration area and evapotranspiration capacity. Considering the water balance, the development of the BTC design model required the: (i) calculation of the infiltration area and (ii) calculation of the evapotranspiration area. Figure 2 presents in more detail the stages of each step.

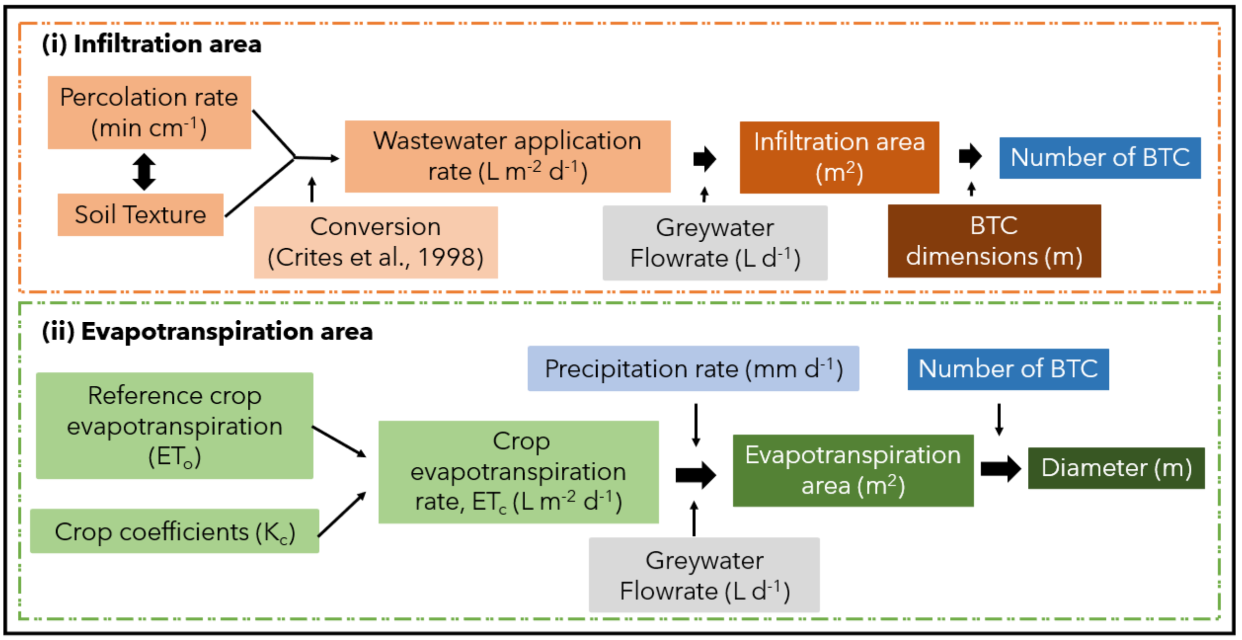


Figure 2: Explanation of the infiltration & evapotranspiration areas estimative for the Banana Tree Circle design.

For the calculations, a dividing factor will be included for the distribution of the greywater flowrate to the infiltration and evapotranspiration systems (distribution factor (df)). This factor can be modified according to the interests of the project (0 ~ 1). For the optimization of the evapotranspiration area the factor will be greater in the calculation of the infiltration area and for the minimization of groundwater recharge the factor will be bigger in the calculation of the evapotranspiration area. For a CB with zero infiltration the system would demand total impermeabilization resulting in an increase of the cost. On the other hand, with zero evapotranspiration it would demand the absence of plants. In order to guide designers, we will suggest df values according to the groundwater depth as shown in Table 3. These values were not validated, and are just a first suggestion for further projects. The minimum distance from the groundwater for the application of wastewater to the soil will depend on local or national guidelines. In Brazil, for example, it is suggested 1.5 m (ABNT, 1997).

Table 3: Suggestions for df values according to the groundwater depth (df_i is the distribution factor in the calculation of the infiltration area; and df_e is the distribution factor in the calculation of the evapotranspiration area).

Groundwater depth	df_i	df_e
deep	< 0.6	> 0.4
shallow	> 0.4	< 0.6

3.2. Model development

3.2.1. Infiltration area

The infiltration area represents the soil capacity to receive all greywater. For the design of the infiltration surface area into the trench, the following parameters need to be considered: the type of soil, percolation rate, hydraulic loading rate, and effluent flowrate (US EPA, 1992; BRASIL, 1997). There is a correlation between soil percolation rate and wastewater hydraulic loading rate for trenches, as shown in Table 4 (Crites et al., 1998).

Table 4: Recommended wastewater application rates for trenches with different soil types and percolation rates (Crites et al., 1998).

Soil texture	Percolation rate (min cm^{-1})	Application rate (L m^{-2} d^{-1})
Gravel, coarse sand	< 0.4	not appropriate
Coarse to medium sand	0.4 – 2	50
Fine sand, loamy sand	2 – 6	30
Sand loam, loam	6 – 12	25
Loam, porous silt loam	12 – 25	20
Silty clay loam, clay loam	25 – 50	8
Clays, colloidal clays	> 50	not appropriate

When knowing the daily soil capacity to receive greywater (L m^{-2} d^{-1}) and the medium daily greywater flowrate (L d^{-1}), it is possible to calculate the required infiltration area (m^2) by Eq. 2.

$$A_i = (n.Q.df_i)/HLR, \quad \text{(Equation 2)}$$

where Ai is the infiltration area (m^2), HLR is the hydraulic loading rate ($L\ m^{-2}\ d^{-1}$), n is the number of users, Q is the greywater flowrate ($L\ d^{-1}$), and df_i is the distribution factor in the infiltration area (0 ~ 1).

After determining the required infiltration area, it is possible to calculate the dimensions of the infiltration trench. Although there is no established definition of the ratio between the diameter and the height of the trench, some factors must be considered, such as the groundwater depth, the surface area availability, and the banana plants root depth. For areas with deep groundwater, the trench could have a higher height, resulting in a smaller diameter, and for locations with more surface availability, the trench could have a larger diameter and, therefore, a lower height. The roots of a banana tree can range from 0.6 to 1.0 m (Bassoi et al., 2001), suggesting that the depth of the infiltration trench should not exceed 1.0 m for the best levels of efficiency for the BTC. Additionally, the maximum trench depth of 1.0 m provides a better structure for the trench walls, easier and more secure maintenance. Considering the review presented in Table 1, it was possible to observe that the infiltration trench diameter ranged from 1.0 to 2.0 m. Diameters greater than 2.0 m are not desirable because it reduces the water distribution to the roots of the plants.

Considering a cylindrical infiltration trench, it is up to the designer to define the dimensions of the infiltration trench considering the depth between 0.6 to 1.0 m and the diameter between 1.0 to 2.0 m. Once the trench area (A_{tr}) for one BTC is defined, by Eq. 3, it is possible to calculate the number of BTC required according to the infiltration area (A_i) by Eq. 4.

$$A_{tr} = \pi\ r(r + 2h)\ , \quad \text{(Equation 3)}$$

$$N = A_i / A_{tr}\ , \quad \text{(Equation 4)}$$

where r is radio of the trench (m), h is the depth of the trench (m), N is the number of BTC required, A_i is the infiltration area (m^2), and A_{tr} is the area of the trench for each BTC (m^2).

3.2.2. Evapotranspiration area

The evapotranspiration area was determined using the crop evapotranspiration rate (ET_c), the precipitation rate (P), and the effluent flow rate (Q) (US EPA, 2002). The ET_c represents the evapotranspiration capacity of the banana trees, and, as in the case of the BTC, determines the maximum daily amount of greywater that the system admits per unit of area (O'Hogain et al., 2011).

The ET_c is defined by:

$$ET_c = ET_o \, . \, K_c \, , \qquad \text{(Equation 5)}$$

where ET_o is the reference evapotranspiration rate (mm d^{-1}), and K_c is the crop coefficient. The ET_o is a local climatic parameter that represents the evapotranspiration power of the atmosphere and is calculated by the Penman-Monteith method (FAO, 1998). This parameter is commonly available from meteorological organizations. The K_c depends on the crop specifications and characteristics, such as species, growth stage, and climate region (Kadlec and Wallace, 2008).

Knowing the evapotranspiration capacity in the planted area (L m^{-2} d^{-1}), the precipitation rate (mm d^{-1}), and the average daily greywater flowrate (L d^{-1}), it is possible to calculate the evapotranspiration area (m^2) using Eq. 6:

$$A_e = (n.Q.df_e)/(ET_c - P.K_i), \qquad \text{(Equation 6)}$$

where A_e is the evapotranspiration area (m^2), ET_c is the crop evapotranspiration rate (L m^{-2} d^{-1}), n is the number of users, Q is the greywater flowrate (L d^{-1}), df_e is the distribution factor for the evapotranspiration area (0 ~ 1; $df_e = 1 - df_i$), P is the precipitation rate (mm d^{-1}), and K_i is the infiltration coefficient. The evapotranspiration area is the space reserved for the cultivation of the banana trees, which are planted around the trench in the BTC system (Figure 1).

The precipitation rate (P) is commonly available from meteorological stations. The infiltration coefficient (K_i) is a parameter related to the factors that influence the inflow of rainwater in the system and can vary between 0 and 1. A lower K_i value means less rainwater is entering into the surface area of the system (Paulo et al., 2019).

After determining the evapotranspiration area (A_e) required, it is necessary to determine the planted area (A_p) for each BTC based on the number of BTC (N) previously established by Eq. 7.

$$A_p = A_e / N, \qquad \text{(Equation 7)}$$

where A_p is the planted area for each BTC (m^2), A_e is the evapotranspiration area (m^2), and N is the number of BTC required.
After determining the planted area (A_p) it is possible to calculate the full radius (R) of the BTC system using Eq. 8:

$$A_p = \pi\ (R^2 - r_i^2), \qquad \text{(Equation 8)}$$

where R is the radius of the superficial area of BTC system (m) and r_i is the radius of the infiltration trench (m). The final superficial area (m^2) of the BTC system can be easily estimated using the R calculated.

3.3. Theoretical case study of the model

For the simulation of the case study, the amount of greywater from the kitchen, bathroom, and laundry produced daily in a household with five people was considered to be equal to 110 liters per person (Morel et al., 2006). The soil in this scenario was considered to be a sandy loam soil (HLR = 25 L m^{-2} d^{-1}) (Crites et al., 1998). The climatic conditions analyzed were similar to those found in the case study of Paulo et al. (2019): ET_o = 4.36 mm d^{-1}; K_c = 2.71; P = 3.85 mm d^{-1}; and K_i = 0.5. In this study, we choose a distribution factor of 0.5 where the greywater will be equally distributed in the dimensioning of the two areas. We considered the dimensions of the BTC infiltration trench as 0.8 m (depth) and 1.5 m (diameter), in function of the limits of 0.6 to 1.0 m and 1.0 to 2.0 for depth and diameter, respectively, as presented previously.

After using equations 2 and 3, we calculated the trench infiltration area (A_i) of **11 m²** and the trench area (A_{tr}) of **5.5 m²**. Considering the equation 4, in this case study will be necessary to construct **two units of BTC**. With equations 5, 6, and 7, we determined the evapotranspiration rate (ET_c) of 11.82 mm d^{-1}, the evapotranspiration area (A_e) of **27.80 m²**, and the planted the radius of the surface area (R) of 2.25 m (Figure 3).

4. Discussion

The development strategy of the design criteria for the BTC followed the principles of a water balance, i.e., the key components of the water cycle of the system: precipitation rate, greywater flow, and evapotranspiration rate. It is the process when greywater and rain inflow to the system and, through the soil-plant interactions, water returns to the atmosphere (Borin et al., 2011). Evapotranspiration is considered the most important factor in this type of technology, precisely because it can determine the water volume that will infiltrate into the soil (Tuttolomondo et al., 2016). Higher evapotranspiration rates result in lower volumes of water for groundwater recharge.

The flow of water infiltrated into the soil is also related to the soil's physicochemical characteristics (Travis et al., 2010). The long-term disposal of greywater on sandy soils shows that they are more susceptible to leaching because of their higher permeability (Siggins et al., 2016). The fact that the BTC is not on an impermeable surface, such as in the constructed wetlands, willow systems, and evapotranspiration tanks (Aiello et al., 2016; Curneen et al., 2016; Paulo et al., 2019), demonstrates that this technology can contribute to groundwater recharge (Radingoana et al., 2020). Therefore, it is crucial to consider the soil hydraulic capacity and the depth of the underlying groundwater to prevent undesired contamination by leaching from the discharge of large volumes of greywater and rainwater (Siggins et al., 2016). This concern highlights the importance of understanding the evapotranspiration process in the hydrology and design of the BTC technology (Borin, 2011).

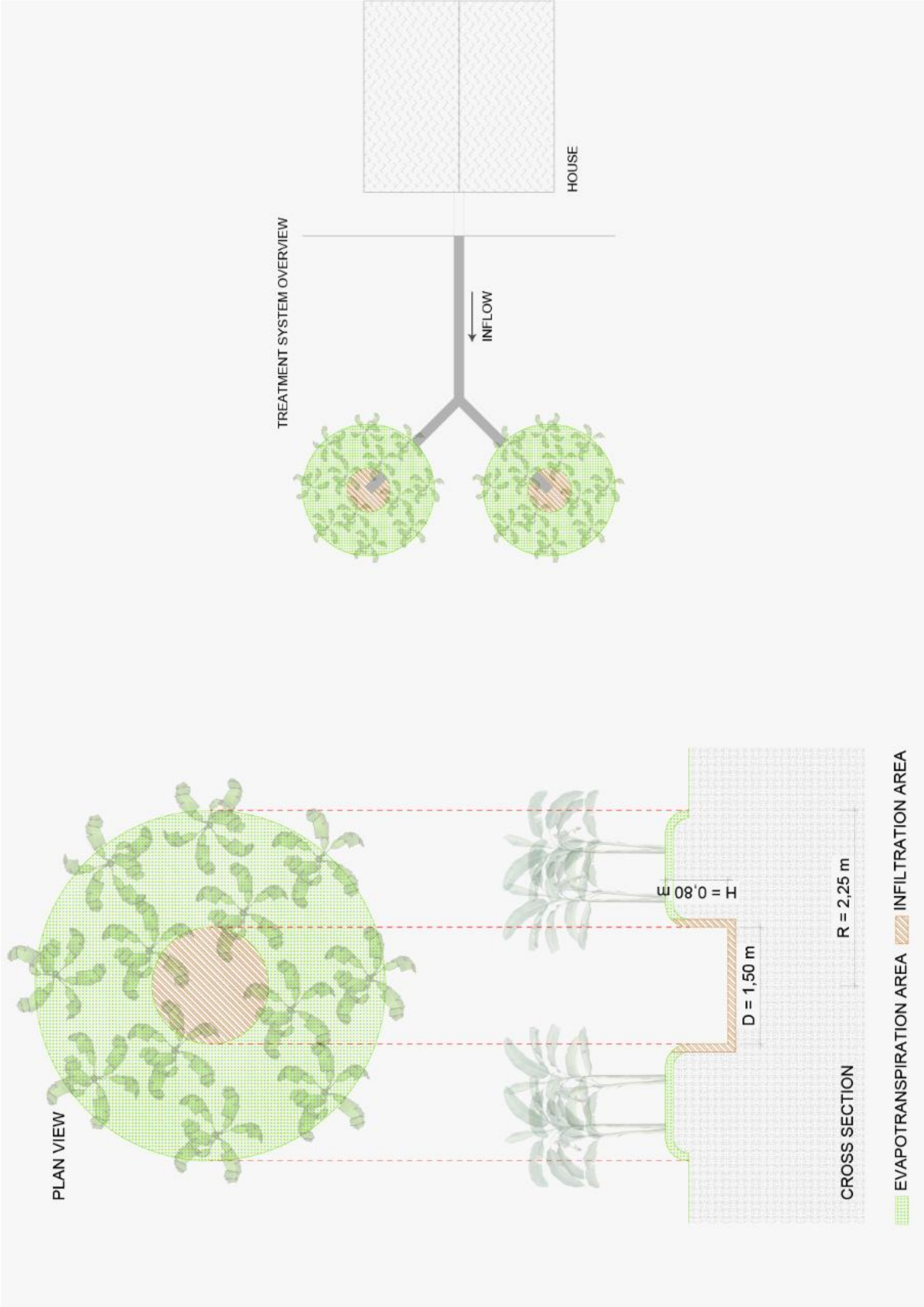


Figure 3: Plan and sectional view of the BTC designed in the case study.

The crop evapotranspiration (ET_c) is commonly applied in irrigated agriculture planning and design (FAO, 1998). The ET_c value indicates the water needs for the plant development. Irrigation design is based on the crop water requirement from the evapotranspiration losses under a balanced environmental condition (Allen et al., 1998), and the aim is to optimize the crop performance under a water-economy basis (Panigrahi et al., 2021). The focus on the rational use of water management directly influences the parameters used in the design of the irrigation systems.

The banana tree is a high water use plant, and productivity tends to increase linearly with transpiration (Panigrahi et al., 2021). In semi-arid regions, the banana tree water consumption can reach 36 L $plant^{-1}$ d^{-1} (Teixeira et al., 2002). One way of estimating the water consumption of banana trees is by considering the plant leaf area, which reaches 2 to 3 m^2 per leaf and 17 to 25 m^2 per plant. A plant with 14 m^2 of leaf area can consume 26 L of water per day (Stover and Simmonds, 1987; Sousa et al., 2011). Then, the common K_c values for the banana crop in irrigation design are close to 1.40 (Santos et al., 2016) or higher in more humid soils (Santosh et al., 2019). These values mean that K_c used in agricultural irrigation design is not appropriate to the BTC technology. In BTC, the system operates predominantly with saturated soils, while in agricultural soils, the main objective is to use the minimum soil moisture to plant production because irrigation is oriented to save water.

Different K_c values are available for different plant species, climate regions, and wastewater treatment technologies. For example, in Brazil, for the evapotranspiration tank (TEvap), which is used exclusively for the treatment of toilet wastewater (blackwater), when planted with banana trees (*Musa cavendishii*), taioba (*Xanthosoma sagittifolium*), and beri (*Canna* spp.), the K_c value used is equal to 2.71 (Paulo et al., 2019). In the same country, the TEvap planted with *Canna* spp. and operated for greywater treatment provides K_c equal to 4.8 (values from 2.5 to 7.7) (Magalhães Filho et al., 2018). The variation in K_c values is due to the higher level of greywater produced compared to toilet wastewater, and this higher volume determined higher evapotranspiration (Magalhães Filho et al., 2018). In Eastern Canada, an experiment with a wetland modeled the evapotranspiration of the willow cultivar (*Salix miyabeana* (SX67)) and measured the mean seasonal crop coefficient equal to 6.4 (annual equal 3.7) (Frédette et al., 2019). In Ireland, the average crop coefficient for the willow evapotranspiration systems (*Salix viminalis*), receiving primary wastewater effluent in the growing season, was 4.82 (from 4.5 to 5.1) (Curneen et al., 2014).

Our analysis shows there are few studies evaluating banana crop evapotranspiration in wastewater treatment systems. In the model simulation process, the K_c value of 2.71 (Paulo et al., 2019) was used for the theoretical case study. The results in our study showed an evapotranspiration rate of 11.82 mm d^{-1} and an evapotranspiration area of 27.80 m^2 for more developed locations (110 L $person^{-1}$ d^{-1} of greywater production). In low- and middle-income countries, the volume of greywater could decrease to 30 L $person^{-1}$ d^{-1} (Morel et al., 2006) and, as a consequence, a smaller evapotranspiration area would be required. As we could see in our case study, when more greywater treatment demand is required, it is necessary to plan for more than one BTC unit. Future studies should test the maximum evapotranspiration area per BTC in locations treating high volumes of greywater.

The BTC is a very simple sanitation technology with low-cost and requiring little engineering work. Its implementation costs are mainly the pipelines, the banana tree crops, and labor work. This system can be considered as a local and cheap greywater management solution, especially in areas lacking sanitation infrastructure, and can help in the elimination of open greywater disposal in developing countries. The BTC also has historical roots. Similar ancient systems, aiming to reduce unsafe greywater management were recorded in Ghana. This African system is a traditional practice, using plants, including bananas, to treat the greywater by phytoremediation and is still in use by the local population (Dwumfour-Asare et al., 2018). Even though they are informal, these practices contribute to improving public health. The BTC contributes to human health by controlling the infiltration of greywater into specific and protected zones. As a consequence, it reduces microbiological contamination through wastewater exposure, the main health risk associated with greywater (Shi et al., 2018).

The lifecycle of a BTC system is still unknown by the scientific community, but recommendations are available for the operation and maintenance of this technology. The procedures required for the system’s operation include banana fruit harvesting, humus removal from the trench, the maintenance of the banana plants (to avoid overgrowth), and the addition of pruning residues to the trench to replace degraded organic material (FUNASA, 2018; Crouch, 2021). The management of the BTC system is designed to be a closed system that offers a sustainable nature-based solution. There is a clear nexus between health, sanitation, and food, demonstrating how this sanitation technology can be innovative in emergency and humanitarian contexts.

5. Conclusions

This paper presents a standardized model for the design of BTC for the treatment of greywater. The model is based on three key parameters: hydraulic loading, soil percolation, and evapotranspiration rate. The simulated results demonstrate that the BTC system is a safe and affordable technology for greywater management, combining zero discharge with local food production. The model provides a tool for a standard design. There is the need for future studies to validate the sustainability and efficiency of the BTC in other regions and, especially as an emergency sanitation solution.

Future studies about the BTC system are also required to develop a better understanding of: (1) the influences of hydraulic loading, soil types, soil structure, and soil bulk density on percolation rates, and (2) the crop coefficient (K_c) for banana plants in wastewater treatment systems, considering plant species, growth stage, and climate. This information would allow for better calibration of the proposed model and contribute to the BTC validation and its large-scale uptake.

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CONSIDERAÇÕES FINAIS

O presente estudo objetivou investigar e contribuir com as estratégias do saneamento ecológico para o uso sustentável da água cinza como recurso hídrico alternativo na agricultura. Dois capítulos foram apresentados visando avaliar: (i) os processos naturais essenciais para o funcionamento de uma solução de saneamento de base-natural, que culminou na proposição de um modelo de dimensionamento, e (ii) os aspectos sociais da aceitação e percepção de riscos e benefícios relacionados ao uso da água cinza na agricultura por parte de um coletivo de técnicos da assistência técnica rural que estão ligados diretamente aos agricultores no estado de Minas Gerais.

O modelo proposto no primeiro capítulo para o dimensionamento do Círculo de Bananeiras no tratamento de água cinza foi baseado em três parâmetros-chave: carga hidráulica, percolação do solo e taxa de evapotranspiração. O modelo fornece uma ferramenta para um projeto padrão que pode ser utilizado no dimensionamento do sistema, muito embora sejam interessantes outros estudos para validar sua sustentabilidade e eficiência. Deixa-se registrado que tais futuros estudos devam considerar as lacunas identificadas e que podem afetar a eficiência do sistema, como: (1) efeito da carga hidráulica, tipo de solo e densidade do solo nas taxas de percolação, e (2) a definição de um coeficiente de cultivo (Kc) para bananeiras específico para sistemas de tratamento de águas residuais, considerando estágio de desenvolvimento da planta e clima. Tais informações auxiliarão na melhor calibração do modelo proposto e contribuirão para a validação do Círculo de Bananeiras e sua adoção em larga escala.

O segundo capítulo destacou a atitude positiva dos técnicos de assistência rural da Emater-MG para o reuso da água cinza na agricultura. Apesar da percepção de possíveis riscos à saúde, os profissionais acreditam que é possível realizar a prática de forma segura com a adoção de técnicas de irrigação e tratamento no local. Os dados levantados indicam a aceitação positiva desse público que tem contato direto com os agricultores e com as suas tomadas de decisão. Destaca-se neste capítulo o maior interesse em participar do desenvolvimento de políticas públicas voltadas para o reuso da água cinza entre os técnicos de regiões de maior escassez de água e em situação socioeconômica mais precária. Estudos futuros com relação a este mesmo tema deverão considerar a aceitação do uso da água cinza na agricultura com outros atores, como os próprios agricultores.

Os resultados dessa dissertação contribuem com o avanço das pesquisas dedicadas às estratégias do saneamento ecológico voltadas para o meio rural. Como produto principal, a contribuição do estudo é o modelo de dimensionamento do Círculo de Bananeiras, uma ferramenta que pode ser base para o desenvolvimento de normas técnicas e manuais para se validar e facilitar a implementação dessa tecnologia no gerenciamento seguro da água cinza e conservação de recursos hídricos. Adicionalmente, o diagnóstico da percepção positiva quanto a reutilização da água cinza na agricultura por parte de técnicos da assistência rural é um primeiro passo para contribuir para com a ampliação das discussões e com a sensibilização para desencadear políticas públicas em prol deste reuso no Estado de Minas Gerais.

APÊNDICE 1

QUESTIONÁRIO

Universidade Federal de Viçosa - UFV
Programa de Pós-Graduação em Agroecologia
Mestrando: Juliano Rezende Mudadu Silva
Orientador: Raphael Bragança Alves Fernandes

PESQUISA SOBRE REUSO DE ÁGUA CINZA NA AGRICULTURA

Por gentileza, leia cuidadosamente as considerações deste documento antes de decidir participar desta pesquisa.

Descrição da Pesquisa

A pesquisa procura entender a aceitabilidade e percepções da prática de reuso doméstico da água cinza na agricultura. **A água cinza é compreendida como a água residual proveniente do chuveiro, lavanderia e pia da cozinha**. Este estudo é conduzido pelo Juliano Rezende Mudadu Silva e Raphael Bragança Alves Fernandes, integrantes do Programa de Pós-Graduação em Agroecologia na Universidade Federal de Viçosa (UFV). O questionário é composto por três seções, com questões de múltipla escolha. O tempo médio esperado para o preenchimento é de **10 minutos**. As respostas do questionário serão coletadas de forma anônima pela plataforma do Google Forms vinculado com o e-mail do pesquisador: julianomudadu@gmail.com.

Essa pesquisa é aprovada pelo Comitê de Ética e Pesquisa da UFV. Para iniciar o preenchimento do questionário é necessário a confirmação da concordância aos termos de confidencialidade presentes no Termo de Consentimento Livre e Esclarecido (TCLE), com um clique em “Confirmo minha participação na pesquisa”, no final dessa página.

Caso tenha alguma dúvida ou colocação sobre a pesquisa, por gentileza contactar via e-mail o mestrando Juliano Rezende Mudadu Silva em julianomudadu@gmail.com ou o Programa de Pós-Graduação em Agroecologia em pos.agroecologia@ufv.br.

Termo de Consentimento Livre e Esclarecido (TCLE)

( ) Confirmo minha participação na pesquisa

SEÇÃO 1 - INFORMAÇÕES DO(A) PARTICIPANTE

1. **Qual a sua identidade de gênero* (***Marque somente uma opção)*
   ( ) Mulher
   ( ) Homem
   ( ) Outro, especifique qual:
   ( ) Prefiro não me classificar

2. **Idade***(Marque somente uma opção)*
   ( ) 18 – 25 anos
   ( ) 26 – 30 anos
   ( ) 31 – 40 anos
   ( ) 41 – 50 anos
   ( ) > 50 anos

3. **Mesorregião de Minas Gerais em que atua profissionalmente ou vive***
   (Marque somente uma opção, preferencialmente onde atua profissionalmente)
   ( ) Noroeste de Minas
   ( ) Norte de Minas
   ( ) Jequitinhonha
   ( ) Vale do Mucuri
   ( ) Triângulo Mineiro e Alto Paranaíba
   ( ) Central Mineira
   ( ) Metropolitana de Belo Horizonte
   ( ) Vale do Rio Doce
   ( ) Oeste de Minas
   ( ) Sul e Sudoeste de Minas
   ( ) Campos das Vertentes
   ( ) Zona da Mata

Nas secções seguintes (2 e 3) indique o seu nível de concordância e discordância das seguintes afirmações sobre a água cinza e seu reuso, considerando a seguinte escala:
1 = discordo totalmente,
2 = discordo,
3 = discordo pouco,
4 = concordo pouco,
5 = concordo,
6 = concordo totalmente

SEÇÃO 2 - ACEITAÇÃO E PERCEPÇÃO EM RELAÇÃO A ÁGUA CINZA E SEU REUSO

Escassez hídrica:

Afirmações	1	2	3	4	5	6
	discordo totalmente	discordo	discordo pouco	concordo pouco	concordo	concordo totalmente
5 - Minha região passou por racionamento de água nos últimos 10 anos.						
6 - Na minha região a escassez de água é comum ao menos uma vez ao ano.						
7- Na minha região a escassez de água tem se agravado com o tempo.						

Vantagens percebidas:

Afirmações	1	2	3	4	5	6
	discordo totalmente	discordo	discordo pouco	concordo pouco	concordo	concordo totalmente
8 - O uso de água cinza na irrigação contribui para a maior disponibilidade de água potável de outras fontes para outros fins.						
9 - É economicamente vantajoso usar água cinza na irrigação.						
10 - O reuso de água cinza promove a recuperação de nutrientes na agricultura.						
11 - É ambientalmente benéfico dispor a água cinza no solo do que no curso d'água.						

Riscos percebidos:

Afirmações	1	2	3	4	5	6

	discordo totalmente	discordo	discordo pouco	concordo pouco	concordo	concordo totalmente
12 - A água cinza contém microrganismos patogênicos.						
13 - A água cinza apresenta risco à saúde humana quando aplicada na irrigação.						
14 - A água cinza da cozinha apresenta menor risco para a saúde humana do que as demais fontes (chuveiro e lavanderia).						
15 - É indiferente separar ou misturar a água cinza pelas fontes geradoras para o reuso agrícola mais seguro, afinal apresentam características semelhantes.						
16 - Sistemas de irrigação com menor exposição da planta à água cinza, como o gotejamento, contribuem para a redução de riscos.						
17 - É viável tratar a água cinza localmente para uso na irrigação a ponto de não causar riscos à saúde humana.						

Aceitação e atitudes:

Afirmações	**1**	**2**	**3**	**4**	**5**	**6**
	discordo totalmente	discordo	discordo pouco	concordo pouco	concordo	concordo totalmente
18 - Eu aceitaria utilizar água cinza como recurso hídrico na agricultura na minha casa.						
19 - Eu me sinto confortável em aplicar água cinza em jardins e árvores.						
20 - Eu me sinto confortável em aplicar água cinza em hortas.						
21 - Eu consumiria produtos de hortas irrigadas com água cinza de outros produtores.						
22 - Eu consumiria produtos de hortas da minha casa irrigadas com água cinza.						
23 - Na minha região , o reuso de água cinza somente é conveniente nos períodos de seca.						
24 - O reuso de água cinza é uma prática promissora para os agricultores familiares da minha região.						
25 - O desenvolvimento de políticas públicas para ampliar o reuso de água cinza seria interessante no contexto da minha região						

SEÇÃO 3 – Novo Paradigma Ecológico

Afirmações	1	2	3	4	5	6
	discordo totalmente	discordo	discordo pouco	concordo pouco	concordo	concordo totalmente
Estamos nos aproximando do limite de pessoas que o planeta Terra pode suportar.						
Os seres humanos têm o direito de modificar o ambiente natural para atender às suas necessidades.						
Quando os seres humanos interferem na natureza, corriqueiramente produzem consequências desastrosas.						
A inteligência humana garantirá que não tornemos a Terra impossível de ser habitada.						
Os seres humanos estão abusando severamente do meio ambiente.						
A Terra tem muitos recursos naturais se apenas aprendermos a desenvolvê-los						
Plantas e animais têm tantos direitos quanto os seres humanos para existir.						

Afirmações	1	2	3	4	5	6
	discordo totalmente	discordo	discordo pouco	concordo pouco	concordo	concordo totalmente
O equilíbrio da natureza é forte o suficiente para lidar com os impactos das nações industriais modernas.						
Apesar de nossas habilidades especiais, os seres humanos ainda estão sujeitos às leis da natureza.						
A chamada "crise ecológica" que a humanidade enfrenta tem sido muito exagerada.						
A Terra é como uma nave espacial com espaço e recursos muito limitados.						
Os seres humanos são destinados para governar o resto da natureza.						
O equilíbrio da natureza é muito delicado e facilmente perturbado.						
Os humanos eventualmente irão aprender o suficiente sobre o funcionamento da natureza para poder controlá-la.						
Se as coisas continuarem em seu curso atual, em breve sofreremos uma grande catástrofe ecológica.						

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