Reuse-oriented decentralized wastewater and sewage sludge treatment for rural settlements in Brazil: A Cost-benefit Analysis

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Abstract
Decentralized Sanitation and Reuse Solutions (DESAR) can contribute significantly to the improvement of wastewater treatment in Small Urbanized Rural Settlements (SURUS). The advantages of DESAR for SURUS include their capability to reduce final treatment costs upon consideration of reclaimed water and sewage sludge reuse for agriculture. In the presented work, we conducted a Costs Benefit Analysis (CBA) of a (DESAR) solution applied in a rural community located in Rio de Janeiro State in Brazil. We applied a Net Present Value (NPV) method to monetize reuse benefits associated with reclaimed water and sewage sludge reuse in agriculture, as well as the environmental benefits related to avoided costs of Biological Oxygen Demand after 5 days (BOD_5) discharges. Based on the (NPV) results of the case study, we found that the monetized benefits of the (DESAR) suggested solution could recover 73% of the total operating and maintenance costs (O&M). Our findings suggest that (DESAR) solutions can respond to the need to reduce costs and improve the nutrient recovery capabilities of sanitation interventions in rural communities.
Keywords
Decentralized Sanitation, Sewage Sludge Reuse, Rural Development, Nutrients Recovery; INTECRAL

INTRODUCTION

Worldwide there is a need for integrative and sustainable Wastewater and Sewage Sludge Treatment Solutions (WASTES) for **S**mall **U**rbanized **R**ural **S**ettlements (SURUS) in low-middle income countries. Nations implementing WASTES for SURUS face a technological, social, economic and institutional challenge. In SURUS areas, factors such as the weaknesses of local governments, low economies of scale achieved by the investments, and limited payment capacities of the communities affected, can restrict investments in WASTES (UN-Habitat 2006). Commonly, these restrictions are more evident in small populations below 20,000 inhabitants, where water resource management programs do not have sufficient funds and the institutions lack management capacities to guarantee investments in this issue (Hophmayer-Tokich 2010). Moreover, SURUS usually have population densities where conventional on-site sanitation facilities prove less cost-effective than collecting and treating wastewater using sewer networks and treatment plants. Small urbanized settlements in rural areas constitute a “grey zone” in which sanitation projects are commonly postponed due to absence of economy of scale and high per capita cost compared to urbanized areas. This situation has produced significant asymmetries for investments in rural and urban areas, especially in less developed nations.

Decentralized Wastewater Management (DWM) concepts are gaining popularity among small communities with low to middle population densities. Decentralization and the potential it provides for the reuse of wastewater in agriculture are considered among the most important factors in terms of the advantages and benefits when treating wastewater in places close to the generation site (Venhuizen 1991; Wilderer & Schreff 2000; Tchobanoglous *et al.* 2004). The possibility of using DWM systems is addressed by (Wang *et al.* 2008) from the point of view named by some authors as decentralized wastewater treatment and reuse (DESAR). Several authors considered the reuse capabilities of decentralized wastewater treatment solutions as an advantage for its application in small communities and rural areas (Massoud *et al.* 2009; van Afferden *et al.* 2010; Lienhoop *et al.* 2014; van Afferden *et al.* 2015). The concept implies wastewater treatment and the reuse of by-products (e.g. reclaimed water, sewage sludge) close to their generation point (Crites & Tchobanoglous 1998).

Interest in DESAR approaches has increased the need to evaluate the economic feasibility of implementing decentralized concepts for wastewater treatment and reuse. Several contributions in the field of economic valuation of DESAR solutions have been presented (Chen & Wang 2009; Gorshkov *et al.* 2014; Lienhoop *et al.* 2014; van Afferden *et al.* 2015). However, there is a need to develop empirical assessments and to establish methodologies aimed at identifying the particularities and difficulties of assessing DWM interventions. DESAR solutions are highly dependent on the local heterogeneity of the social, environmental, geographical, economic and technological conditions (Liang & van Dijk 2010). In this context, techno-economic studies are needed in order to demonstrate the feasibility of DESAR concepts for SURUS from a systematic perspective. Moreover, these studies must include in the economic valuation of the treatment solutions all potential benefits that may arise from the reuse practices.

In Brazil, around 75% of the rural population (equivalent to 23 million inhabitants) does not have access to wastewater treatment facilities (Costa & Guilhoto 2012). IBGE (2011) reported that 75% of the total rural population is forced to make do with inadequate sanitation services: only 40.7% of the 75% use cesspits and no more than 24% have septic tanks connected to the sewer network (Lopes da Silva, 2013). These systems do not satisfy the Brazilian legal parameters for wastewater treatment disposal (Gallotti 2008). Moreover, they have the potential to cause environmental and social problems (e.g. groundwater pollution, water related-diseases). Even though the domestic wastewater pollutants account for 0.1% of the pollutants present in water, they are responsible for 80% of the wastewater related diseases (Gallotti 2008). These figures reflect the importance of sanitation investments in WASTES solutions for SURUS.

In this paper, we performed a Costs-benefit Analysis (CBA) of a theoretical DESAR solution for a rural community (1000 PE) located in a rural area of Rio de Janeiro State in Brazil. The analysis aims to identify the cost recovery capabilities of the WASTE solutions, especially in terms of operating and maintenance costs. The CBA was achieved by monetizing reuse benefits associated with reclaimed water and sewage sludge reuse in agriculture, as well as the environmental benefits related to Avoided costs of BOD_5 discharges. The indicator generated by the study can point the way to the introduction of decentralized wastewater and sewage sludge treatment and management concepts in rural areas and in communities across the world with similar sanitations needs.

METHODOLOGY

We propose the following steps in order to proceed with the economic evaluation of the DESAR solutions.

a. Socio-economic survey of the selected community.
b. Geographic Information System Analysis: This procedure can be used to assess the topographic and hydrological conditions of the study area.

c. Population density analysis based on the socio-economic survey as well as satellite imagery. The densities of building and distances between them can be used to determine the requirements placed in the sewer network.
d. Estimation of required lengths in the sewer network based on remote sensing.
e. Identification of available areas for the potential location of wastewater and sewage sludge treatment facilities.
f. Selection of the most suitable wastewater and sewage sludge treatment technologies.
g. Wastewater quality standards and sludge quality parameters.
h. Cost estimates for construction, land acquisition, as well as operating and maintenance costs for the required wastewater and sewage treatment facilities.
i. Estimation of economic benefits associated with the treatment solutions: We propose to apply: (i) avoided costs for BOD_5 discharges based on the local environmental legislation; (ii) avoided costs associated with sludge management (transportation, drying and final disposal), (iii) avoided costs related to water uptake for irrigation and (iv) the benefits of sludge reuse as fertilizer.
j. Calculation of cost-recovery capabilities, especially in terms of operating and maintenance costs.

In the DESAR solution considered in this study, we applied a Costs Benefit Analysis (CBA) based on the Equation (1) below.

$$NPV = \sum_{t,i}^{T,N} \frac{B_{i,t} - C_{i,t}}{(1+r)} \qquad \text{Eq 1}$$

where, *Bi* is the value of the benefit item *i*, and *Ci* is the value of the cost of item *i*. The Net Present Value *NPV* is the difference between Cost and Benefits. If the result of the calculation is $NPV>0$, then the project is economically viable, while the project is not viable in economic terms if the value is $NPV<0$. The best option will offer the highest CBA (Pearce *et al.* 2006). The CBA must include feasible financial indicators like Net Present Value (NPV). The NPV measures the economic value of a project. It is defined as the net profit discount shown in Equation 1 in which *t* is the time horizon of the project, NVP_t is the net profit at time and *r* is the discount rate. The CBA takes *NPV* as the main financial indicator decision rule. A project with a positive *NPV* value is viable, and if the *NPV* is negative the project should be rejected (Pearce *et al.* 2006)

The cost and benefits consideration for the DESAR system are described in Figure 1

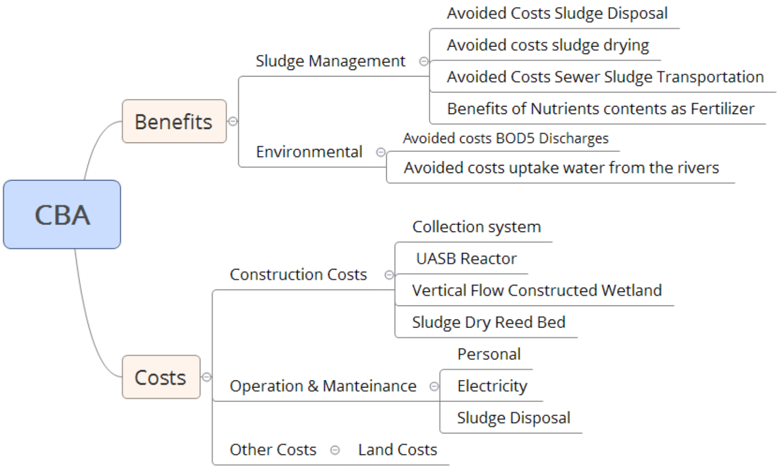

Figure 1 Benefits and Cost considered for the DESAR system

CASE STUDY

Background

The project “Integrated Eco Technologies and Services for a Sustainable Rural Rio de Janeiro INTECRAL”, initiated by the German Ministry for Education and Research (BMBF), sets out to assist the promotion of sustainable approaches for sanitation in rural areas. One key aspect of the project outcomes is the development of Integrated Wastewater Treatment solutions for rural areas of Rio de Janeiro State. Given that agriculture is the main economic activity in the target communities, DESAR solutions consider the economic benefits of reusing stabilized sludge as a fertilizer substitute. This integrative approach has the potential to offer significant benefits in the sanitation conditions in rural areas of the country, and can also provide direct environmental-economic benefits due to the substitution of chemical fertilizers.

For the case study we chose community Barracão dos Mendes, located in the municipality of Nova Friburgo 136 km from the state capital of Rio de Janeiro in Brazil. At the community cesspits are used for collecting wastewater. This system does not have a pipe for the draining of the wastewater, and no treatment take place on them. Cesspit tanks are normally installed per house but there can be shared several families. The systems usually present different problems such as bad odours. Furthermore, cesspits can overflow especially during the rainy season (Segovia 2014) . It often presents leaks or can sink into the ground. The main problem of this system is the high groundwater pollution. In general, less than 10% of the wastewater is collected in the study area, which indicates the inadequacy of the of sewer network in the region (See Figure 2).

The population of the study area in 2014 was: 528 residents, with 3.85 inhabitants per house. The estimated future population for the study area was calculated based on a local survey and satellite images of the buildings. The population is expected to grow to 1000 inhabitants by 2034.

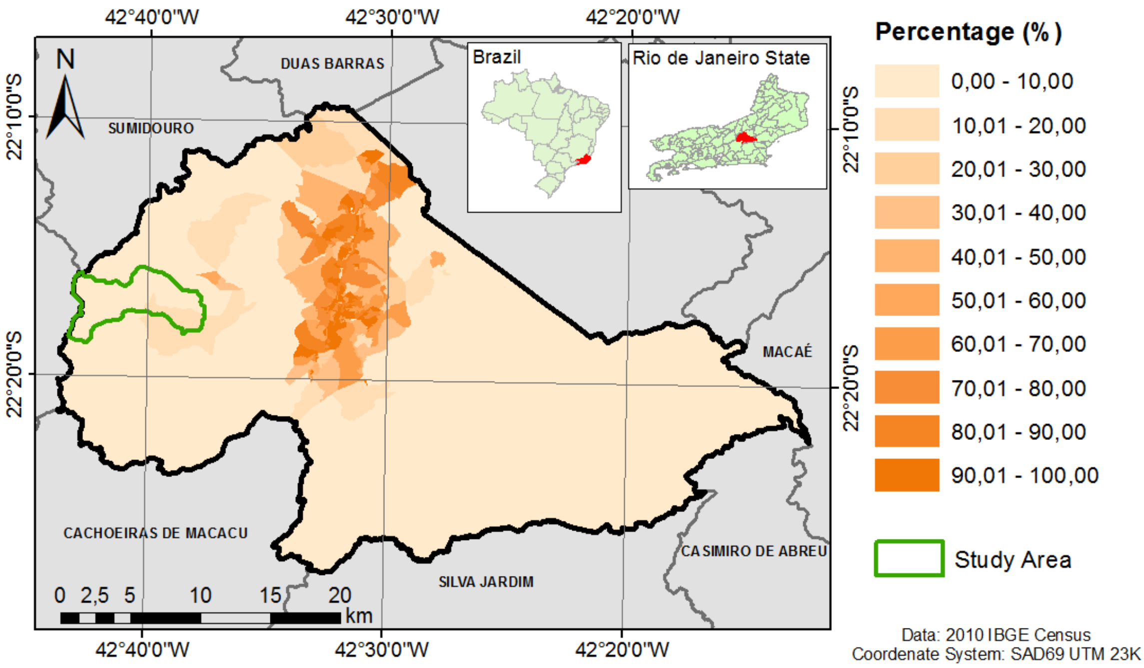

Figure 2 Percentage of the population in the Municipality of Nova connected to wastewater collecting systems based on Census 2010 (IBGE 2010). Study area Barracão dos Mendes present 0% connection to collecting system

Population Density

Taking as a reference the recommendation of the European Economic and Social Committee, installed sewerage networks should not exceed 5-10 m drain length per capita, equivalent to 100-200 inhabitants/km of sewage network. In the selected area, we used satellite images and digital elevation models developed in the field to estimate a total sewer length of 2575 m, equivalent to 2.5 m per capita. This value justifies the construction of a sewage network that would reflect population densities values similar to urban areas in the city of Rio de Janeiro, which has a population density of 6.200 inhabitants per square kilometre (Cox 2013). At the community population densities above 5000 inhabitants per square kilometre based on satellite imagery were found (see Figure 3). For this reason the wastewater treatment solution require the installation of a wastewater collecting system.

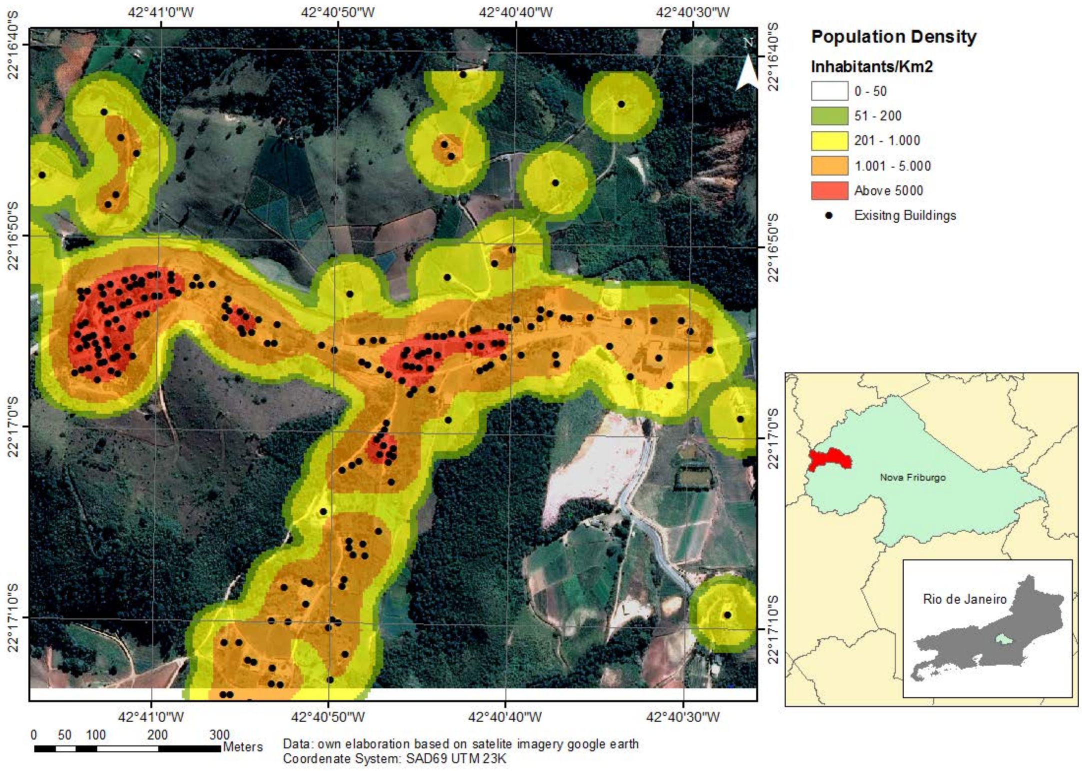

Figure 3 Population density at the community of Barracão dos Mendes

Selected Technologies for Wastewater and Sewage Sludge Treatment

The selected technologies were the most relevant approaches in the field of decentralized wastewater treatment. For the case study, we selected an Upflow Anaerobic Sludge Blanket (UASB) combined with Vertical Flow Constructed Wetlands (VFCW). The selected treatment train is a low-cost alternative for rural sanitation that allows reuse practices (de Sousa *et al.* 2001; El-Khateeb & El-Gohary 2003; Halalsheh *et al.* 2008; Ruiz *et al.* 2008). Concerning sewage sludge management, we evaluated an on-site sludge treatment facility using Sludge Drying Reed Beds (SDRBs) (Nielsen & Willoughby 2005). As a result, it was possible to highlight the importance of, and experience with, anaerobic systems in this country. Moreover, we considered the use of these systems combined with constructed wetlands, which have proven suitable in decentralized solutions (Wendland *et al.* 2006).

Sludge treatment wetlands (SDRBs) or sludge drying reed beds are recent treatment systems based on the operation of wetland systems. They are constituted by shallow tanks that are filled with layers of gravel and emergent vegetation such as Phragmites australis plants (Cole 1998; Uggetti *et al.* 2011). The sludge is spread and stored on the surface of the beds and the most of its water content is lost by plants evapotranspiration and by water draining through the gravel filter layer, leaving a concentrated sludge residue on the surface. When the maximum storage capacity is reached, after a resting period end, the biosolids are withdrawn to start a new operating cycle. The product is suitable for land applications (Nielsen & Willoughby 2005); although in some practical cases it is post-treated to improve increase sludge stabilization and hygienisation (Zwara & Obarska-Pempkowiak 2000). This system improves the physicochemical properties and soil fertility due to the increase of organic matter and nutrients (Silveira *et al.* 2003; Nogueira *et al.* 2013).

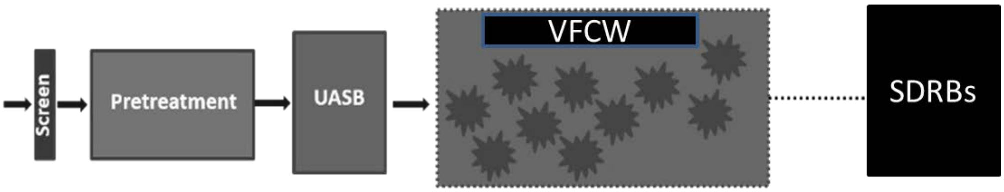

Figure 4 Selected treatment train for the DESAR solution within the case study

Legal Framework

According to its 1988 Constitution, the Brazilian government is responsible for the restoration and preservation of natural ecological processes. To this end, the government in 1997 passed federal law no 9433 on the management of water resources, also known as the "Water Law", which establishes the National Policy of Water Resources (PNRH) and creates the National System of Water Resources Management (SINGREH). State law no 3239, introduced in Rio de Janeiro one year later, has a corresponding purpose. However, there are more recent federal laws on sanitation, namely no 11445 of 2007, which established the guidelines for National Policy and which is defined in greater detail in law no 7217 of 2010. The National Environment Council (CONAMA), the Brazilian Association for Technical Standards (ABNT) and, in Rio de Janeiro, the State Environment Institute (INEA) are responsible for regulating the technical and environmental parameters that complement the legislation.

Expected Effluent quality by wastewater treatment plant

We consulted the current Brazilian legislation, resolution 357 from 2005, which was enacted by the National Environmental Council (Conselho Nacional do Meio Ambiente) CONAMA. The applicable standard is DZ 215.R4 from 2007 in respect to BOD. The BOD load rate applied in our case (201 to 1000 users) must achieve 65% of BOD and TSS removal.

Expected Sludge Quality by sewage sludge treatment plant

The DESAR solution observes the procedures and Brazilian legal requirements for sludge use and disposal, including restrictions and precautionary measures. Resolution 375, issued in 2006 by the Brazilian National Environment Council (CONAMA 2006), regulates only the concentration of heavy metals and some pathogens. Table 2 shows the main parameters that the sludge must satisfy according to CONAMA; it also includes parameters that are cited in literature for the various technologies – Sludge Treatment Wetlands (STW), Centrifuge and Composting. Although there are no standard values or settings for this type of systems, there are some suggestions reported in the literature (Metcalf & Eddy 1991; Uggetti *et al.* 2010; Uggetti *et al.* 2011). The efficiency levels that can be achieved with the SDRBs regarding the % TS and % VS/TS are comparable to those obtainable with other technologies such as centrifugation and composting (Uggetti *et al.* 2010).

Table 1 Characteristic parameters of treated sewage sludge or bio solids generated by different treatments and those established by CONAMA.

Parameter	**Uggeti et al 2010 and 2011**			**CONAMA 2006**
	SWT	Centrifuge	Composting	
TS(%)	20-24	18	83	-
VS(%TS)	38-39	73.4	62	-
TNK (%TS)	2.6-3.4	6.4	2.5	-

Ptotal (%TS)	0.08	1.84	2.3	-
Cu (mg/kg)	48-55	518	388	1500
Zn (mg/kg)	533-551	807	1087	2800
Pb (mg/kg)	43-52	60	110	300
Cd (mg/kg)	0.6	2	1.5	39
Ni (mg/kg)	29-36	15	54	420
Cr (mg/kg)	49-55	40	95	1000
Hg (mg/kg)	3.5-5.3	4	-	17
Fecal bacteria indicators				
Salmonella	Absence in 25 g	-	-	Absence in 10 g
Fecal coliforms	<3	-	-	<1000 MPN/g TS
Viable helminthic eggs	-	-	-	<0.25 eggs/ g TS

RESULTS

Cost Calculation

Three principal costs were considered to estimate total cost: (I) Initial investment costs, which include the city network, house connection costs and the installation of the UASB, VFCW and SDRB, (II) land costs and (III) O&M costs for the UASB and VFCW, and SDRB, which comprises staff costs, energy costs and other costs. These final costs also cover energy requirements and personnel requirements (Table 3). All costs of wastewater infrastructure were estimated based on fieldwork, local prices and literature review. Equation (2) shows the quantification of aggregated costs.

$$\sum C_i = C_1 + C_L + C_{O\&M} \qquad \text{Eq 2}$$

in which C_I represents the initial investment cost, C_L the land cost and the $C_{O\&M}$ the operating and maintenance costs. Calculation of costs for sanitation investment projects has a monetary value. In most cases it is based on literature review and empirical values acquired by wastewater engineering companies.

Table 2 Costs in Brazilian Real R$ 2014[1] associated with DESAR infrastructure presented in Net Present Value for a project life span of 20 years and a discount rate of 12%.. Design data: PE = 1000; Flow Rate =130m^3/d; BOD$_5$=350 mg/l

Item	**Value in R$**
Total Capital Costs [a]	660,000
Total Land Costs [b]	25,000
Total O&M Costs [c]	111,000

(a) *Including the treatment train UASB+VFCW+SDRB. Construction Costs UASB based on (von Sperling & Salazar 2013); CC of VFCW and SDRBs using C= 1650,4*Q^{0,697} (Cardona 2005); Sewer Network costs based on own calculations using satellite images and digital elevation models.*

(b) *Land Requirements: UASB = (0,05 m^2.c^{-1}) based on von Sperling (1996); VFCW = (1 m^2.c^{-1}) from Hoffmann et al. (2011); SDRM = (0,3 m^2.c^{-1}) from (Uggetti et al. 2011) ; land costs assumed to be 20 R$/m^2 based on local survey.*

(c) *Operating and Maintenance costs: UASB = (15 R$/c.a) according to (Jordao & Volschan 2009); VFCW and SDRB assuming (0.5 US$/c.a) based on (Koottatep et al. 2001).*

Benefits Calculation

Wastewater treatment projects generate environmental and social benefits (e.g. health improvements, water polishing, recreational, water reuse, etc.) (OECD 2011) These benefits should be included in feasibility studies. The main problem is the complexity of quantifying wastewater treatment benefits in monetary terms, as they are not registered directly by the market and they have to be calculated based on non-market values (Fiorio *et al.* 2008). In this study, we maximized the potential environmental-economic benefits from the local reuse of treated wastewater and sewer

[1] Values in Brazilian Reals R$ October 2014 (1R$ =0.4073USD)

sludge. Additionally, we evaluated as a benefit the avoidance of costs for the transport and disposal of sludge in landfills and the elimination of costs of BDO_5 discharges in bodies of water.

Avoided costs of BOD_5 Discharges

Implementation of the DESAR system will lead to a reduction in BOD_5 discharges in bodies of water. This reduction will curtail water pollution and hence can be considered a benefit. In order to evaluate the reduction in BOD_5 discharge, we considered the kg amount of BOD_5 generated for the system on a yearly basis multiplied by the value of BOD_5 discharge in Brazilian reals (0.0763 R$/kg), as established by CEIVAP directives (CEIVAP 2014), for the Paraiba do Sul basin, discounted for each year. Equation 3 shows the calculation of this benefit.

$$AC_{BOD5} = 365 \sum_{i=1}^{n} Q_{BOD5}\, P_{BOD5} \qquad \text{Eq 3}$$

in which AC_{BOD5} represents the avoided cost of BOD_5, Q_{BOD5} the quantity of BOD_5 and P_{BOD5} the public unit prices of BOD_5 organic discharge.

Avoided the Cost of Uptake Water for Irrigation

The DESAR system also considers water reuse for irrigation purposes, which will present a further environmental benefit in terms of preserving bodies of water. The uptake water payments for irrigation in the community were calculated based on water directives according to CEIVAP (2014). The calculation of this benefit is shown in Equation 4, in which AC_{UWI} represents the avoidance of costs of uptake water for irrigation purposes, Q_{ww} the quantity of wastewater treated every day and P_{wc} the price of water catchment, as established for the region (CEIVAP 2014). This value is discounted for each year.

$$AC_{UWI} = 365 \sum_{i=1}^{n} Q_{WW}\, P_{WC} \qquad \text{Eq 4}$$

Avoided the Cost of Sludge Transportation and Disposal

This aspect considers local reuse of sludge for agricultural purposes. The cost incurred for the disposal and transportation of the sludge produced by the treatment plant to a sanitary landfill would be eliminated. Removing this cost factor would constitute a benefit, which was calculated based on Equation 5.

$$AC_{SIT\&D} = QSl_i * (PSl_T + PSl_D) \qquad \text{Eq 5}$$

in which the $AC_{SIT\&D}$ represents Avoided the Cost of Sludge Transportation and Disposal, QSl_i is the annual sludge production in T/a for the DESAR system, PSl_T the price for sludge transportation to the sanitary landfill and PSl_D denotes the price for sludge disposal. This value is discounted for each year. The transportation costs of R$11.84/t were estimated by assuming 25 km for sludge transportation, as based on previous estimates for this distance in the country according to (Quintana et al. 2012).

Benefits of Nutrient Contents as Fertilizers

This aspect considers the quantity of nutrients contained in wastewater that can be absorbed by the crops and soil. The study focused on the local reuse of sludge produced by the DESAR solution. This method will contribute to reducing the amount of agrotoxins used by local farmers, and hence to the cost of fertilizers. The study assumed that sludge produced can be obtained every five years. The calculation considered merely the volume of nitrogen, phosphorus and potassium (NPK) present in the sludge. The sludge quantities produced in kg/d were calculated based on 10,000 inhabitants and according to Andreoli et al. (2007). The values of per capita sludge mass production are expressed in $gSS/inhabitant^{-d}$, while the per capita volumetric production is described by

L/inhabitant[-d.] The nutrient quantities were estimated based on typical values reported in commercial fertilizers (Metcalf and Eddy, 2003) and biosolids from wastewater treatment plants in Brazil (Andreoli et al. 2007). The nutrient benefits are shown in Equation (6):

$$BN = \sum(Q_{Ni} * P_{Ni}) \qquad \text{Eq 6}$$

in which Q_{Ni} is the production of nutrients obtained from the sludge (NPK) and P_{Ni} is the updated market price of each nutrient in Brazil.

In order to estimate the benefits of nutrients, we assumed a generation of 42 tons/year of sludge from the wastewater treatment plant, according to the flow rate and typical values for UASB + aerobic post treatment as defined by Andreoli et al. (2007). Therefore, nutrient production was calculated as N= 1390 $kg.a^{-1}$P; =970 $kg.a^{-1}$; K= 128 970 $kg.a^{-1}$.

$$B\Sigma B_i = AC_{BOD5} + AC_{UWI} + AC_{SlT\&D} + BN \qquad \text{Eq 7}$$

The total benefits (*Bi*) from implementation of a DESAR the analysis considered a time horizon of 20 years. Based on the European Commission guidelines for the calculation of this analysis, the construction phase, in which the initial investment and land costs for the DESAR system will be incurred, is defined as Year 0. Meanwhile, the operating and maintenance costs will be incurred annually once the system becomes operational. Benefits will ensue from the moment at which the system is put into operation in Year 1.

Table 3 Summary of Benefits associated to DESAR infrastructure presented in Net Present Value for a 20-year project life span and a 12% discount rate (Ministerio da Cidades 2011). Values in Brazilian reals R$ October 2014 (1R$=0.4073 USD). Design data: PE = 1000; Flow Rate =$130m^3/d$; BOD_5=350 mg/l

Items	Total Benefit in R$
Avoided Costs of BOD_5 Discharges [a]	11,000
Avoided Costs of Uptake Water for Irrigation [b]	4000
Avoided Costs of Sludge Transportation and Disposal [c]	26,000
Benefits for Nutrients contents as Fertilizer [d]	41.000

(a) *Discharge fee for kg/BOD_5 = 0,0763 R$/kg from CEIVAP (2014); uptake water for irrigation = 0,0109 R$/$m^3$ from CEIVAP (2014)*
(b) *According to the flow rate and typical values for UASB + aerobic post treatment from Andreoli et al. (2007)*
(c) *Sludge transportation assumed from previous estimations in the country from (Quintana et al. 2012) estimated in R$11,84/t*
(d) *Derivate from local survey including fertilizer prices for mineral fertilizer costs NPK*

The economic benefits associated with the DESAR solution are presented in Figure 1. The chart expresses as an NPV value of all the monetized benefits associated to the decentralized wastewater treatment solution. The chart shows the nutrients from sewage sludge, which constitutes the major potential cost recovery factor, followed by the elimination of costs relating to the avoidance of sewage sludge transportation, drying and final disposal in landfills. This result illustrates the importance of considering local sewage sludge treatment in order to reutilize all nutrients directly in agriculture.

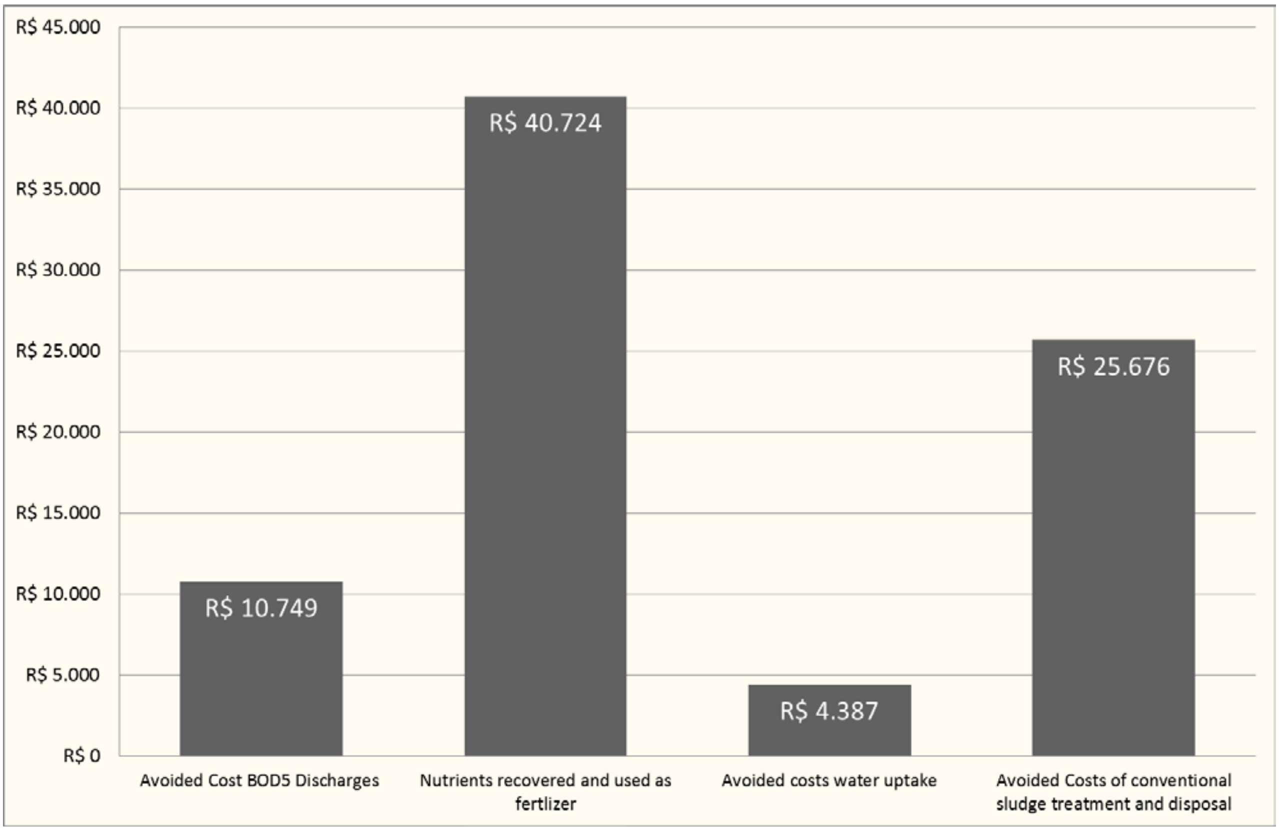

Figure 5 Distribution of economic benefits after 20 years of operation of the DESAR wastewater and sludge treatment solution applied in the community of Barracão dos Mendes in Rio de Janeiro, Brazil

RESULTS AND DISCUSSION

The results of the CBA – considering a 20-year project lifespan and a discount rate of 12% (Ministerio da Cidades 2011) are presented in Table 4. The results revealed that DESAR provides a strong recovery cost capability. We found that monetized benefits led to the recovery of 74% of total O&M costs. Concerning reuse, nutrient recovery presented the major benefit. We found monetized values of R$108 per ton of treated sludge (SDRB). The cost benefits acquired through the avoidance of sludge transportation and disposal in a landfill reached 0.026 R$/m^3. The benefits of Avoided costs associated with BOD_5 discharges and water uptake for irrigation amounted to 0.0108 R$/m^3 and 0.0044 R$/m^3, respectively.

Table 4 Cost –Benefit Analysis considering 20 years of operation of DESAR Solution.

Costs and Benefits	**Values in R$**
Net Present Value NPV	-713.817
Total O&M Costs after 20 Years Operation	111.031
Total Benefits after 20 years operation	81.537
Recovery Costs associated to O&M Costs	73%

The need for sewage sludge management is considerable and represent commonly 20- 60% of the total operation costs of conventional wastewater treatment facilities (Uggetti *et al.* 2010). In our study, sewage sludge reuse accounts for a significant proportion of the potential benefits shown by DESAR. Several studies have discussed the importance of reusing treated wastewater and wastewater sludge for agricultural purposes in Brazil (Andreoli *et al.* 2008; Lino & Ismail 2013), highlighting the benefits of their reuse to improve soil fertility. In addition, there is an urgent need for companies, institutions and governments to share technical and operational information in regard to processes for using sludge in agriculture and to provide support (training) to farmers who receive the sludge.

CONCLUSIONS

DESAR solutions are an alternative means of improving wastewater treatment and agriculture production in rural communities of Brazil. Local sludge treatment allows for nutrient recovery and thus enables the development of new markets associated with agro-ecology practices. Therefore, DESAR solutions present an attractive opportunity for farmers to acquire new income by combining wastewater and sludge treatment with the respective economic benefits of their reuse.

When applied to DESAR solutions, CBA is a powerful tool in displaying the total benefits of sanitation projects. Monetization of additional economic benefits is possible; including environmental benefits associated with Avoided the cost of uptake-water and payments for BOD_5 discharge. Therefore, this study makes a methodological contribution to decision-making processes in future investments in rural communities with low to middle population densities in rural areas. Hence, rural settlements are priority areas for future investments in sewer infrastructure designed for the recollection, treatment and disposal of domestic wastewater and sewage sludge in many regions across the world.

The DESAR solution responds to the need to improve the current sanitation situation in small communities worldwide as a contribution to food security development. For instance, the use of nutrients can be allocated to the development of new green markets involved in agro-ecology production, and can therefore forge a link to sustainable sanitation concepts within ecological agriculture markets. The use of these methodologies proves attractive in the generation of new incomes in the field of local water and sanitation, green practices, and the promotion of an integrative approach that combines wastewater treatment with the reuse of nutrients in rural areas worldwide.

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