Chapter 18
Reuse-Oriented Decentralized Wastewater and Sewage Sludge Treatment for Small Urbanized Rural Settlements in Brazil: An Environmental Cost-Benefit Analysis

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Abstract Latin-American countries lack efficient solutions for wastewater and sewage sludge treatment. In particular, small urbanized rural settlements (SURUS) in many of these countries face significant challenges with respect to the selection and operation of sustainable sewage treatment facilities. Decentralized sanitation and reuse (DESAR) solutions can significantly contribute toward the improvement of wastewater sanitation coverage in SURUS in Latin-American regions. The major advantages of DESAR for SURUS are a reduction in final treatment costs because these systems allow for water reclamation and sewage sludge reuse for agriculture. To reflect the applicability of DESAR on a regional scale, we present here an integrative assessment, including a cost-benefit analysis (CBA) and geographic information systems (GIS) surveying, as a "decision support methodology" for conducting environmental-economic analyses. As a case study, this methodology was applied to six SURUS located at the Rio Dois Rios basin of Rio de Janeiro state. The CBA shows that DESAR could recover between 15% and 34% of total operational and maintenance costs for SURUS populations between 222 and 1,585 inhabitants. The findings suggest that DESAR systems can respond to the need to reduce

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costs and improve nutrient recovery capabilities of sanitation interventions in rural communities.

Keywords Decentralized sanitation · Rural development · Sludge reuse Nutrient recovery · INTECRAL project

18.1 Introduction

Integrative and sustainable wastewater and sewage sludge treatment solutions (WASTES) for rural areas in low- to middle-income countries are keys for achieving the Sustainable Development Goals (SDGs). However, implementing WASTES is a challenge for both planners and decision-makers, especially in small urbanized rural areas (SURUS) with population densities similar to those found in urban areas. WASTES are normally not implemented in SURUS, in part, due to the absence of economies of scale and the high costs per capita compared to urbanized areas (UN-Habitat 2006; Hophmayer-Tokich 2010). Yet, SURUS generally have population densities for which conventional on-site sanitation facilities prove less cost-effective than collecting and treating wastewater via sewer networks and treatment plants (Bakir 2001). Therefore, SURUS are becoming "gray areas" in which implementation of WASTES is commonly postponed. This produces significant asymmetries for investments between rural and urban settlements, especially in middle to less developed countries (Cardona et al. 2016).

The past decade has seen increased interest in the potential of decentralized wastewater management (DWM) systems to address sanitation challenges in SURUS. In contrast to their centralized counterparts, decentralized approaches are designed to treat the effluent close to the point of generation (Crites and Tchobanoglous 1998). They require less funds to be allocated to the collection and transportation of effluent (Otis and Mara 1995; Bakir 2001) while supporting local reuse of treated wastewater and partial recovery of treatment costs (Massoud et al. 2009; Lienhoop et al. 2014; van Afferden et al. 2015). As a result, they balance cost and effectiveness more successfully in areas with low to medium population densities (Otterpohl et al. 1997; Wilderer and Shereff 2000).

Unfortunately, the selection and implementation of DWM systems in a number of low- and middle-income countries have presented many challenges. In particular, the methodology for the design of DWM systems should ensure that local conditions are well understood and, furthermore, that local reuse practices are appropriately integrated for maximum economic benefits. In this context, local conditions encompass technical, social, economic, and environmental aspects. Provided that sound techno-economic feasibility studies are conducted, decentralized sanitation and reuse (DESAR) systems can assist rural communities in the development and implementation of low-cost, simple to operate effluent treatment systems (Lens et al. 2001).

This chapter summarizes the results of the "Integrated Eco technologies and Services for a Sustainable Rural Rio de Janeiro (INTECRAL)" project, funded by the German Ministry of Education and Research. The project aims to address issues pertaining to sustainable sanitation solutions in rural areas of Rio de Janeiro state (RJ). One key objective is to perform an environmental CBA of decentralized wastewater and sewage sludge treatment solutions in small urbanized rural areas within the Rio Dois Rios Basin. This study summarizes the methodology developed and applied and highlights the necessary steps for conducting CBA within SURUS at a regional level.

18.2 Problem Setting and Case Study Region

In Brazil, 75% of the total rural population receives inadequate sanitation services (Costa and Guilhoto 2012). 73% of the 5,564 Brazilian municipalities are small and medium towns of maximum 20,000 inhabitants. Only 55% of these municipalities have sewer systems, and 52% of them use septic tanks for primary treatment (IBGE 2010b). Some authors have further emphasized that treated wastewater in many rural areas does not meet the minimum Brazilian legal requirements for effluent release (Gallotti 2008). This situation is likely to instigate wider environmental and social problems, such as groundwater pollution and outbreaks of waterborne diseases (Segovia 2014; Cardona et al. 2016).

Although the municipal basic sanitation plan is the first mandate under the Brazilian national sanitation policy, the provision of sanitation services in rural areas remains largely unattended. The lack of environmental awareness and technical expertise means that sanitation plans are poorly formulated and access to state and federal resources is frequently denied. Therefore, planning instruments for WASTES in Brazilian SURUS are important from both an environmental and an economic perspective in order to improve the decision-making process in the basin.

18.2.1 Selected Basin, Rio Dois Rios

As a part of the INTECRAL project, the catchment of the Rio Dois Rios (Fig. 18.1) was selected based on its great lack of wastewater treatment infrastructure. The conditions within the Rio Dois Rios Basin are representative of the situation in many SURUS in Brazil, where the wastewater infrastructure investment has been very poor in comparison with urban areas. For instance, according to the 2010 IBGE census, only 11.3% of the total Rio Dois Rios population (51,332 people) were connected to a sewer network, 23.9% relied on septic tanks, and 64.7% had no access to wastewater treatment facilities (IBGE 2010b). The basin drains 3,200 km^2 and covers nine municipalities that are home to 220 thousand inhabitants. The Rio Dois Rios Basin includes 82 micro-basins with decentralized administrative structures

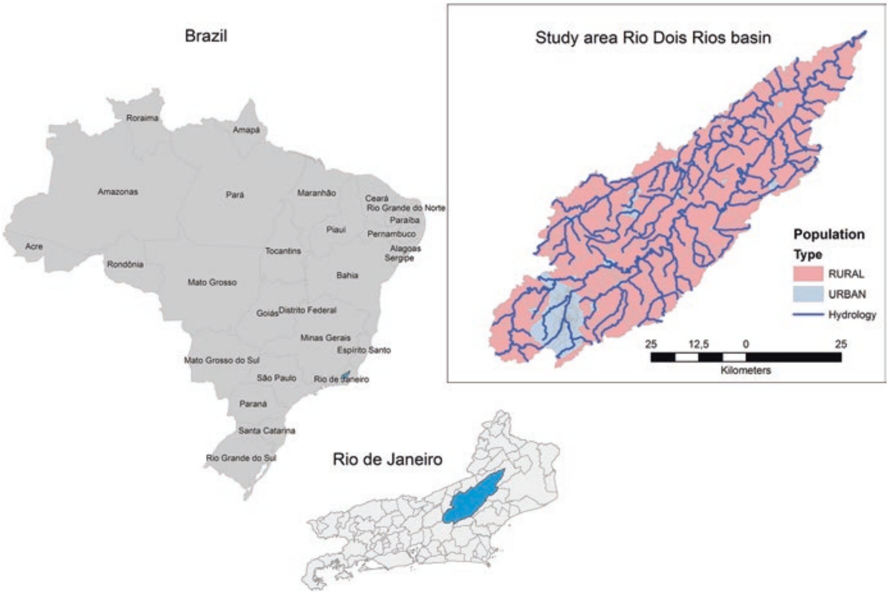

Fig. 18.1 Study area basin Rio Dois Rios, Rio de Janeiro, Brazil (own elaboration)

and community-based integrations to facilitate water resources management and encourage sustainable agricultural practices. Moreover, we chose the basin due to the significant amount of existing information related to socioeconomic and water/wastewater infrastructure surveys.

In this context, identification of additional water resources for irrigation and methods of nutrient recovery for fertilizer substitutes provided opportunity for the application of DESAR.

18.3 Materials and Methods

The DESAR environmental and economic valuation methodology, developed by Cardona et al. (2016) within the framework of the INTECRAL project, includes the following steps:

1. Identification of SURUS priority areas:
    (a) Regional assessment, including a socioeconomic survey of the selected community.
    (b) Population density analysis, using geographic information systems (GIS) surveying (based on the socioeconomic survey and satellite imagery).
    (c) The densities of building and distances between them can be used to determine the requirements placed on the sewer network.
    (d) Connection degree.
    (e) Future population.

2. Definition of wastewater quality standards and sludge quality parameters
3. Selection of most suitable SURUS communities for WASTES
4. CBA of selected WASTES applied to identified SURUS
    (a) Cost estimates for construction, land acquisition, as well as operating and maintenance costs.
    (b) Estimation of economic benefits associated with the treatment solutions. In order to calculate the economic benefits of DESAR solutions in monetary terms, we followed a methodology proposed by Chen and Wang (2009). In this approach, a net benefit value (NBV) model quantifies the benefits of costs avoided. For our case, the following benefits were chosen because of local environmental legislation:
        (i) Avoided BOD_5 (5-day biochemical oxygen demand) discharge penalties
        (ii) Avoided costs associated with sludge management (transportation, drying, and final disposal)
        (iii) Avoided costs related to uptake of water for irrigation
        (iv) The benefits of sludge reuse as fertilizer
    (c) Estimation of net present value (NPV) for selected SURUS communities.
5. Calculation of cost-recovery capabilities, especially in terms of operating and maintenance costs

18.3.1 Identification of SURUS Priority Areas

18.3.1.1 Population Density Analysis and Future Population Estimation

Population density estimates were obtained based on a socioeconomic survey (IBGE Census 2000 and 2010a) and a rural census (IBGE 2007) and were supported by ArcGIS software. The 2007 IBGE census guided the identification of rural buildings, and necessary adjustments were performed manually using ArcGIS satellite imagery. The point density tool (ArcGIS), with a person per square kilometer resolution, determined a cell size of 25 m and a rectangular neighborhood setting of 125 m to identify the densest communities (exceeding 2,000 inhabitants per km^2) (Fig. 18.2b–c). The population density value was assumed based on the fact that the maximum urban population density in RJ by the year 2010 rose to 5,265 inhabitants per km^2 (IBGE 2010a). In our case, we chose a lower population density value because remote sensing techniques identified that most of the SURUS had densities under 2,000 inhabitants per km^2.

In the six selected communities, the number of residential houses was evaluated using satellite imagery. Assuming that 3.5 inhabitants occupy each house, the present community size was evaluated for the year 2017. Using arithmetical projection methods based on previous censuses (IBGE 2000, 2010a), population growth in the communities of interest was estimated in the range of 0.95–1.72. This result was used to forecast population expansion.

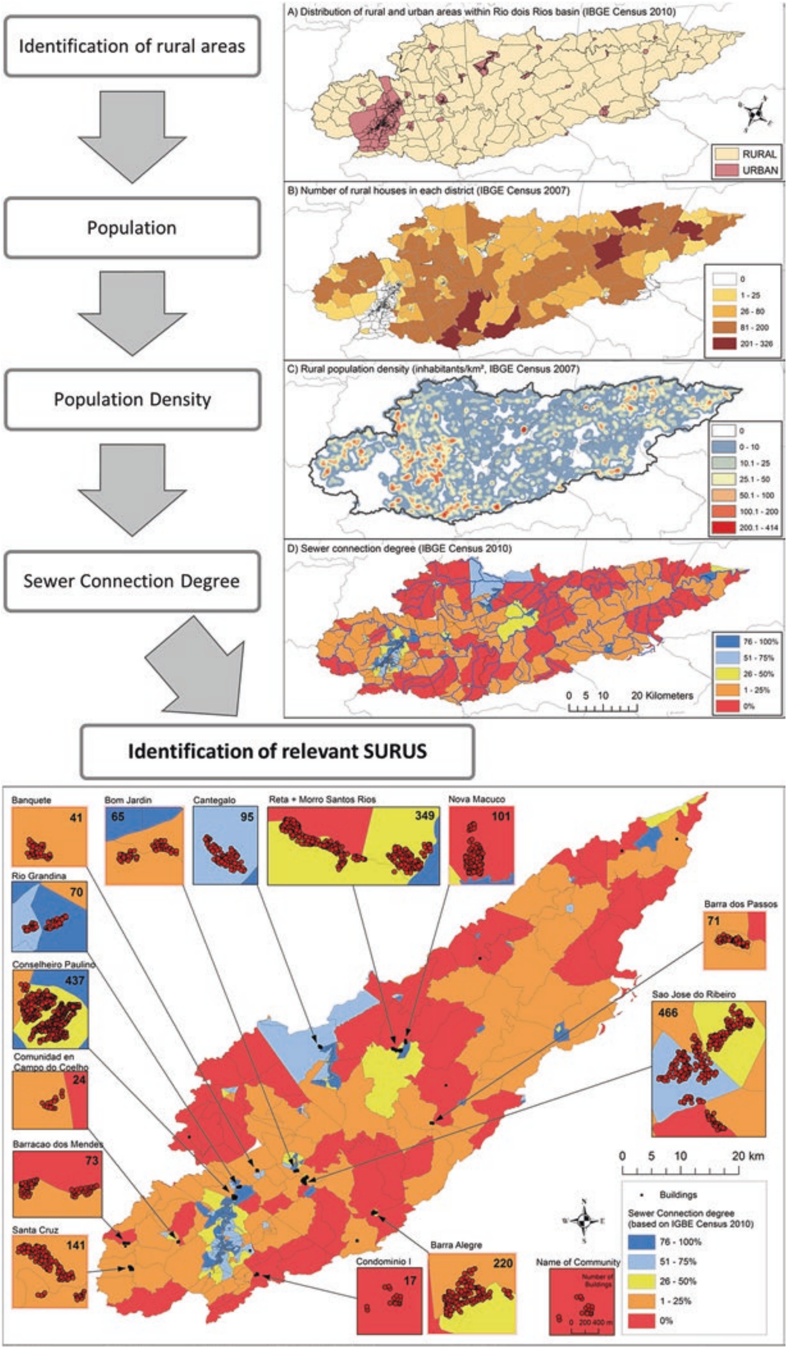

Fig. 18.2 GIS-based analysis of population density and degree of sewer connection within the Rio Dois Rios basin (own elaboration)

18.3.1.2 Connection Degree Estimation

The connection degree is the percentage of the settlement that is connected to a sewer network. This, however, does not necessarily mean that it is linked to a treatment facility. Based on the 2010 IBGE census (2010a), six communities were selected based on a degree of sewer connection (below 30%) and community size (minimum 40 houses). A detailed analysis of Barracão dos Mendes had already been performed (Segovia 2014; Cardona et al. 2016). For this reason, the community was not evaluated further but rather used as an exemplary case for the adaptation of various indicators, such as inhabitants per household or sewer line requirements per capita (Segovia 2014; Cardona et al. 2016). The locations of the remaining six settlements can be seen in Fig. 18.2c.

As a result of the GIS-based assessment, six SURUS (Table 18.1) were identified as priority settlements for conducting a CBA analysis on decentralized WASTES.

Table 18.1 Population, infrastructural, and effluent quality characteristics of six Rio Dois Rios rural communities

SURUS	Current buildings	Pop 2010[a]	Pop change rate in 10 years[b]	Pop in 2017[c]	Pop in 2037[c]	Connection degree[d] (%)	Pop without wastewater treatment system[e]	Equivalent daily BOD_5 load (kg)[f]
C1	101	354	1.72	533	1585	0	1585	63.42
C2	71	249	1.54	342	808	1.12	799	31.98
C3	220	770	0.95	745	679	15	577	23.09
C4	141	494	1.07	517	588	3.2	570	22.78
C5	41	144	1.17	161	222	16.23	186	7.43
C6	65	228	1.14	249	323	20.5	257	10.27

Nova Macuco (C1), Barra dos Passos (C2), Barra Alegre (C3), Santa Cruz (C4), Banquete (C5), Bom Jardim (C6)

[a] Based on IBGE population census, 2010a

[b] Population change rate in 10 years is calculated based on the geometrical progression method, $IG = (P_2 - P_1)/P_1$, where P_1 is the population by year 2000 (IBGE 2000) and P_2 is the population by year 2010 (IBGE 2010a)

[c] Population between 2017 and 2037; the latter is based on the geometrical progression method, $P_n = P \times (1 + IG/100)^n$, where IG = geometric mean (%), P = present population, and n = number of decades

[d] Connection degree calculated based on the data extracted from the water and sanitation infrastructure survey (IBGE 2010b)

[e] Population without wastewater treatment system is calculated based on the formula, $P_{WWT} = P_n \times (100 - CD)$, where P_n is the current total population and CD is the connection degree

[f] Equivalent daily BOD_5 load calculated based on the formula $BOD_5 = (P_{WWT} \times BOD_{Ca})/1000$, where P_{WWT} is current population without wastewater treatment system and BOD_{Ca} is BOD load per inhabitant per day ($g/c.d^{-1}$). BOD load was assumed to be equal to 45 ($g/c.d^{-1}$) (Mara 2013)

18.3.2 Selection of WASTES Technology and Quality Standards

The following criteria were considered for the selection of suitable WASTES:

- Low operation and maintenance costs
- The Brazilian wastewater effluent standards (Brazilian National Environmental Council (CONAMA) Resolution 357 of 2005), BOD discharge limits (CONAMA DZ 215.R4 of 2007), and sewage sludge standards (CONAMA Resolution 375 of 2006)
- The possibility of treating sludge locally

As a result, upflow anaerobic sludge blanket (UASB) technology combined with a vertical flow constructed wetland (VFCW) was proposed and is considered to suit the socioeconomic climate in rural areas (de Sousa et al. 2001; El-Khateeb and El-Gohary 2003; Wendland et al. 2006; Halalsheh et al. 2008). In addition, sludge treatment wetlands (STWs) (Uggetti et al. 2010), which are shallow tanks filled with gravel and planted with emergent vegetation, such as *Phragmites australis*, were incorporated into the design (Cole 1998; Uggetti et al. 2011). The treatment train utilized for the present study is shown in Fig. 18.3.

Other technologies such as sequential batch reactors (SBRs) and membrane bio reactors (MBRs) can be also considered as decentralized treatment units for the community. However we did not consider them due to their higher running costs and the qualifications required for the staff for operation.

18.3.3 Cost-Benefit Analysis

The CBA model presented in Eq. (18.1) was developed for evaluating DESAR in the selected SURUS and simulates the most relevant parameters for an environmental-economic analysis of the communities considered:

$$\text{NPV} = \sum_{n}^{t=0} \frac{(Bi - Ci)_t}{(1+r)^t} \tag{18.1}$$

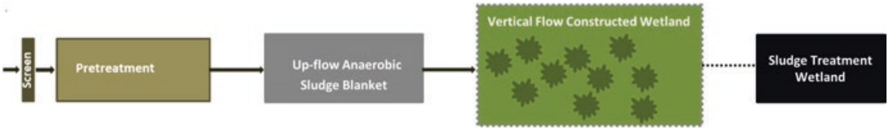

Fig. 18.3 DESAR treatment train implemented in the present case study (Source: Cardona et al. 2014)

where NPV is the net present value, B_i is the value of the benefit item i, C_i is the value of the cost of item i, r is the discount rate, t is year, and n is analytical horizon in number of years. The NPV measures the economic value of a project. The CBA takes NPV as the main financial indicator decision rule. A project with a positive NPV value ($NPV > 0$) is economically viable, and if the NPV is negative ($NPV < 0$), the project should be rejected. The best option will offer the highest CBA (Pearce et al. 2006).

18.3.3.1 Economic Benefit Estimation

Using the CBA approach, various models were generated to quantify the economic benefits that are associated with WASTES and are determinant to improving the recovery of operating and maintenance costs. In the present study, benefits associated with the following were evaluated:

- Reuse of water and sewage sludge for agriculture
- Avoidance of BOD_5 discharge penalties
- Avoidance of conventional sludge transport, treatment, and disposal costs

The economic benefits were calculated according to the methodology and equations proposed by Cardona et al. (2016) and are summarized in Table 18.2.

18.3.3.2 Cost Estimations

The costs associated with sanitation projects are assigned a monetary value that, in most cases, is based on a literature review and the empirical values that were acquired from wastewater engineering companies. Using the available literature and the empirical cost data obtained from the analysis of Barracão dos Mendes, (i) the capital investment requirements for the sewage network and (ii) operation and maintenance costs for the associated facilities were calculated. All costs were calculated in Brazilian reals.[1]

Equation (18.2) shows the quantification of aggregated costs:

$$\sum C_I = C_1 + C_L + C_{O\&M} \tag{18.2}$$

where C_I represents the initial investment cost, C_L the land cost, and the $C_{O\&M}$ the operating and maintenance costs.

Table 18.3 summarizes the assumptions made and parameters defined for the cost estimation of the WASTES investigated in the present work.

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[1] Values in Brazilian reals (R$) October 2014 (1R<Footnote ID=”Fn1”><Para ID=”Par47”>Values in Brazilian reals (R$) October 2014 (1R$ = 0.4073 USD).</Para></Footnote>#x00A0;= 0.4073 USD).

Table 18.2 Estimation of the economic benefits of the applied DESARs (Cardona et al. 2016)

Benefits	Equation	Description of variables
Avoided sludge transportation The evaluation of costs for sludge transportation and disposal ($C_{ST\ \&\ D}$)	$C_{ST\ \&\ D} = Q_{Si} \times (C_T + C_D)$	Q_{Si} is annual sludge production (T/year), C_t is costs for sludge transportation, and C_D is costs for sludge disposal
Benefits of nutrient compounds[a] Nutrients presented in treated wastewater by DESAR solutions can be applied as fertilizer substances for soil and crops in agriculture. Produced sludge can contain nitrogen, phosphorus, and potassium. The production of nutrients was estimated for UASB	$BN = \sum (Q_{Ni} \times P_{Ni})$	Q_{Ni} is produced nutrients from sludge (kg/year), and P_{Ni} is the market price of nutrients in Brazil (Marcon et al. 2015)
Avoided costs of uptake water The uptake water payments for irrigation in the community were calculated based on water directives CEIVAP (2014)	$AC_{UWI} = 365 \sum_{n}^{i=1} Q_{WW}\, P_{WC}$	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
Avoided costs of BOD_5 discharges 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)	$AC_{BOD5} = 365 \sum_{n}^{i=1} Q_{BOD5}\, P_{BOD5}$	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

[a] The total sludge produced by the UASB reactor under aerobic conditions was calculated using the methodology of Andreoli et al. 2007. The applied COD load (kg COD/d) of the sludge generated in the UASB reactor was computed according to $COD_{\text{load applied}} = Q \times COD_{\text{typical}}$, where Q is the estimated flow rate (m^3/d) and COD_{typical} is the influent COD concentration of typical wastewater (947 mg/L) (Andreoli et al. 2007). The quantity of sludge production is $= Y \times COD_{\text{load applied}}$, which is a function of the applied COD load and the sludge mass production, $Y = 0.18$ kg suspended solids/kgCOD (Andreoli et al. (2007).

18.4 Results and Discussion

A CBA was performed based on a simulation model after 20 years of operation, and the results are presented in terms of NPV (Table 18.4) and specific treatment costs (Table 18.5). DESAR projects in selected SURUS in Rio Dois Rios turn out to be clearly beneficial for recovery operation and maintenance costs. CBA models for DESAR were generated using two different biosolid market prices, namely, a worst case of R$ 30.83 and a best case of R$ 167.32 per ton (Marcon et al. 2015). For

Table 18.3 Assumptions and parameters applicable to the WASTES cost estimates

Parameter units	Value	Source
Design parameters		
Water consumption (l/(c·d))	250	(Andreoli et al. 2007)
Biological oxygen demand (mg/l)	463	(Andreoli et al. 2007)
Chemical oxygen demand (mg/l)	947	(Andreoli et al. 2007)
Inhabitants per household	3.5	(Cardona et al. 2016)
Costs parameters UASB + VFCW		
Sewer line requirements per capita (m)	2.5	(Cardona et al. 2016)
Land prices ($R/m)	16	(Segovia 2014)
Construction costs in USD for VFCW = $1650.4 * Q^{0{,}697}$		(Cardona 2005)
O&M in EUR UASB+VFCW = $402.55 * (\mathrm{PE})^{0.454}$		(van Afferden et al. 2015)
Costs parameter STW		
O&M costs for STW STW = $16.19 * (\mathrm{PE})^{0{,}8589}$		(Uggetti et al. 2011)
Costs parameter sludge transportation and disposition		
Transport costs = (pf/cap) *2D		(Quintana et al. 2012)
Where pf (assumed price per km) = R$3.79/km, cap = cargo capacity of the truck assumed in 16 t. Two times distance for collecting and disposition (2D)		
Landfill disposal (R$/T)	120	(Cardona et al. 2016)
Benefits of nutrient recovery Best case (R$/T)	164.32	(Marcon et al. 2015)
Benefits of nutrient recovery Worst case (R$/T)	30.83	(Marcon et al. 2015)
Financial parameters		
Evaluation period in years	20	
Discount rate	12%	(Ministerio da Cidades 2010)

instance, community C1 with a projected population of 1585 inhabitants by year 2037 showed the highest cost recovery potential (34% in the best case and 24% in the worst case), while the smallest community C5 with an estimated population of 222 inhabitants by year 2037 showed only 12% in the best case and 8% in the worst case (Fig. 18.4). From an economic (cost efficiency) perspective, the model results suggest that on-site treatment of wastewater and sewage sludge should be given first priority.

A clear correlation between the number of beneficiaries (community inhabitants) and the economic benefits obtained was observed. Communities with a greater

Table 18.4 Costs and benefits associated with DESARs presented in net present value for a project life span of 20 years and a discount rate of 12%. Values in thousand Brazilian reals R$ October 2014 (1R$ = 0.4073 USD)

Item	Units	*c1*	*c2*	*c3*	*c4*	*c5*	*c6*
Costs							
Total capital costs	R$	730	420	370	330	150	210
Total O&M costs in 20 years	R$	303	219	202	189	120	143
NPV of project costs	R$	1,060	657	583	528	277	354
Benefits *(After 20 years of operation)*							
Avoided costs BOD_5 discharges	R$	26	13	11	10	4	5
Avoiding costs uptake water for irrigation	R$	11	5	5	4	1	2
Avoided costs sludge transportation and disposal	R$	22	11	9	8	3	4
Benefits for nutrient contents as fertilizer	R$	45	23	19	17	6	9
NPV of project benefits	R$	104	53	45	39	15	21
Recovery of O&M costs	%	34%	24%	22%	21%	12%	15%

Table 18.5 Specific treatment costs and benefits based on net present value for a project life span of 20 years. Values in thousand Brazilian reals R$ October 2014 (1R$ = 0.4073 USD)

Item	Units	*c1*	*c2*	*c3*	*c4*	*c5*	*c6*
Flow rate	m^3/d	317	162	136	118	44	65
Specific treatment costs STC							
STC (including investments and O&M)	$R\$/m^3$	0.44	0.53	0.56	0.59	0.81	0.71
STC (O&M)	$R\$/m^3$	0.12	0.18	0.19	0.21	0.35	0.29
STC (O&M – Benefits)	$R\$/m^3$	0.08	0.13	0.15	0.17	0.31	0.25

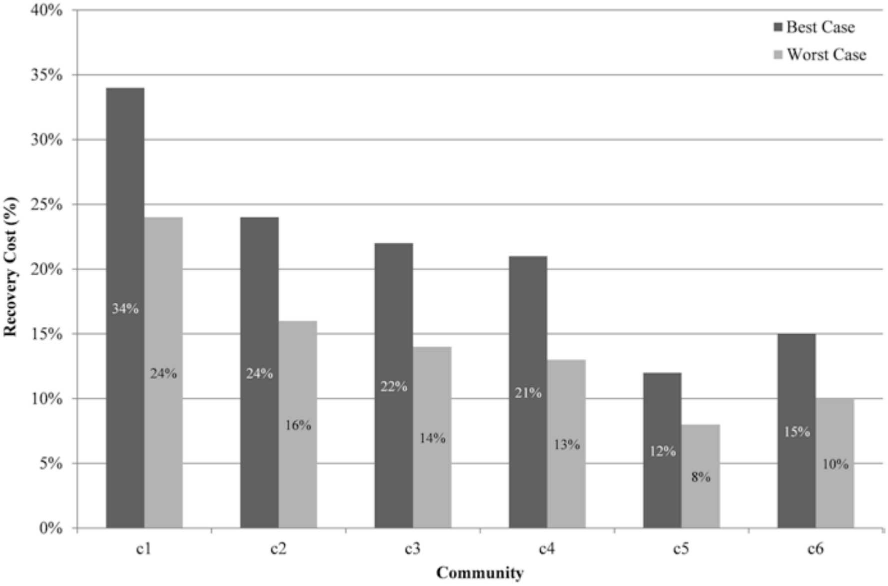

Fig. 18.4 Comparison between recovery of operation and maintenance costs considering best and worst cases scenarios

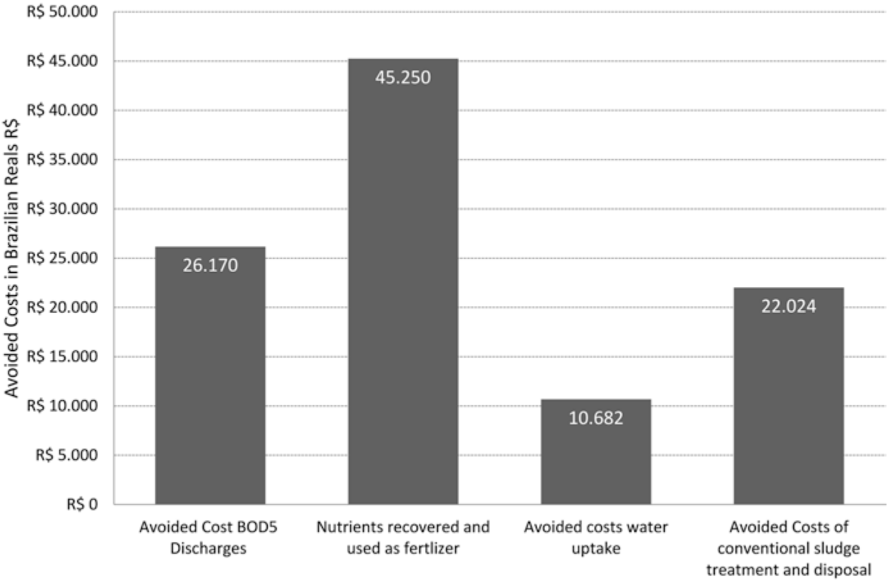

Fig. 18.5 Comparison of economic benefits of DESARs implemented in community C1 (1,585 inhabitants) considering the highest market price for biosolids as chemical fertilizer substitutes (164.32 R$/T)

number of inhabitants can recover a larger portion of the operation and maintenance costs. This can be explained by the larger quantities of biosolids and water for reclamation and irrigation generated, as well as the proportional costs of BOD discharge avoided by implementing decentralized WASTES.

Under the best case biosolid's market price scenario, it was observed that the benefits associated with nutrient reutilization made the biggest contribution to cost recovery (Fig. 18.5). In the worst case scenario, considering the lowest biosolid market price, costs avoided from BOD_5 discharge contributed the least to cost recovery (Fig. 18.6). Cost reduction due to avoidance of sludge transportation and disposal was the second most sensitive parameter (Figs. 18.4 and 18.5).

The STCs related to O&M vary from 0.12 to 0.35 R$/m^3. Integration of the operational and maintenance benefits associated with a decentralized system yielded a noticeable STC reduction (Table 18.5) and reflects potential for a full recovery of O&M costs using DESARs. This trend has been also reported in previous studies conducted in Jordan by van Afferden et al. (2015).

The dry session in 2015 drastically affected the availability of water for consumption and irrigation. This highlighted the fact that alternative water sources for irrigation of agricultural land can play a significant role in reducing the effects associated with drought and climate change. Therefore, water management programs in the region are currently reviewing reuse practices and investigating alternative water resources.

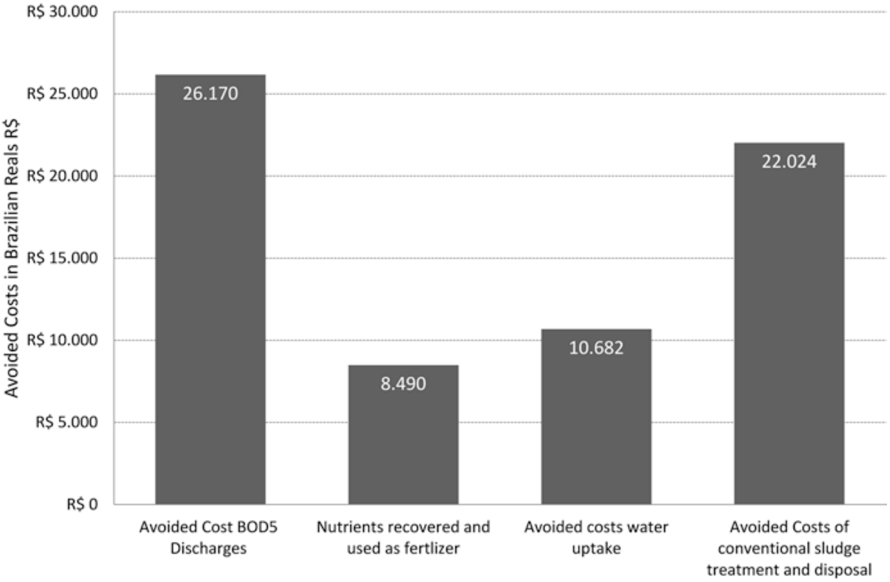

Fig. 18.6 Comparison of economic benefits of DESARs implemented in community C1 (1,585 inhabitants) considering the lowest market price for biosolids as chemical fertilizer substitutes (30.83 R$/T)

Over the past few years, Brazil has been faced with an economic crisis, which resulted in an increase in the price of chemical fertilizers. As a result, alternative nutrient sources, such as treated sewage sludge, are gaining attention from farmers as a fertilizer substitute (Rigo et al. 2014). Additionally, a large portion of the land in the selected study area has been degraded due to poor agricultural practices and over farming (Sattler et al. 2014). Consequently, farmers are looking for affordable nutrient sources to rehabilitate the unproductive areas. In this context, DESARs are well suited to respond to both sanitation needs and the improvement of agricultural practices.

18.5 Conclusions

The efficacy of DESARs is highly dependent on local social, environmental, geographical, economic, and technological conditions. Combining CBA with GIS surveying can guide the decision-making process for implementation of decentralized wastewater and sewage sludge treatment. This approach is also a powerful tool for determining the economic benefits associated with DESARs considering the relevant socioeconomic, geographical, and environmental conditions. The present work has shown that geographical and spatial dimensions are critical in identifying suitable SURUS communities at a regional level.

SURUS communities can benefit from DESARs in terms of provision of improved sanitation services. In addition, treatment of sewage sludge locally using DESAR provides famers in rural areas with an alternative source of chemical fertilizers. Hence, eco technologies for wastewater treatment and sludge stabilization have great potential in rural areas and, more specifically, in SURUS, due to low operational costs, ease of integration into such communities, and nutrient recovery capabilities. These advantages facilitate decentralized system implementation in Brazilian hydrological basins while promoting green markets and agroecological practices.

Additionally, DESAR makes wastewater treatment more affordable by maximizing the benefits associated with O&M cost recovery. This increases the opportunities for initiating wastewater treatment projects in rural areas with low payment capacities.

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