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The Costs and Benefits of Greywater Reuse in a University Academic and Residential Building

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Abstract: *This paper reports on an investigation carried out to determine the spectrum of costs (economical and environmental) and benefits (economical and environmental) that can be achieved through greywater reuse for toilet flushing at a university academic and residential building. Cost-Benefit analysis was performed over a 10 year design life by calculating the Net Present Value (NPV), Cost-Benefit ratio and Payback period. Economical costs were calculated based on the capital and recurrent expenditure on the greywater system while environmental costs were calculated using the Disability Adjusted Life Year index which quantifies the impact of the system on human health. The economical benefit was calculated based on the potable water saved from reuse while environmental benefit was quantified based on the savings achieved from the sewage bill. Results show that project is currently not economically viable based on payback period of 20 years and 133 years at WITS and UJ respectively. Also a negative NPV and Benefit/Cost was recorded at both sites. The study concludes that there is a possibility of economic benefit at WITS (non-residential) assuming the number of toilet currently in use is increase with an increase in the price of potable water.*

Keywords: *Costs and benefits of greywater reuse for toilet flushing; economical, environmental and social;*

1. Introduction

South Africa is a water scarce country with a highly skewed rainfall distribution pattern and an annual average mean annual precipitation of 502 mm compared with the world average of 860 mm. Stream flows are at relatively low levels for most of the year, and the infrequent high flows that do occur, happen over limited and often, unpredictable periods. For instance, Johannesburg which is regarded as one of the cities with densely populated residence buildings is not located near any major fresh water source. This calls for urgent concern for developing various water savings strategies such as greywater reuse. It has evident that greywater recycling offers reduction in urban potable water demand up to 30% - 70% (Radcliffe, 2003). The replacement of the scarce high quality drinking water with less quality ones to perform such functions as flushing of toilets, fire fighting, garden and lawn irrigation will help towards the sustainability of the valuable resource.

Currently, greywater reuse is not yet widely practiced in South Africa, hence the lack of legal standards and guidelines regarding to its reuse. The general public is also discouraged from installing the greywater system due to high cost of installation and maintenance. One of the major concerns of the general public is the economic benefit in terms of the implementation of greywater water reuse system. People regard greywater reuse as a pure scientific process that cannot be practicalized. The major concern of most people is that the price of water is very cheap, and that investing in greywater reuse may not bring any return on their investment. The raised concerns have called for research regarding the economic assessment of greywater reuse. (Dolnicar et al. 2007)

Cost benefit analysis is an economic assessment tool that can be used in assessing if an investment will provide satisfactory returns. It forms a major part of a feasibility study that allows decision makers to make judgment on the implementation of reuse projects by evaluating the benefits of a project from its investments over a determined planning horizon. In a water reclamation project, economic assessment is carried out by clearly identifying the project objective, alternative solution, service area, market assessment, environmental impact, treatment and distribution facilities required (Biagtan, 2008, Adewumi 2010). A methodology to assess the economic feasibility of a water reuse project taking into account not just the internal impact, but also the external impact (environmental and social, etc) and the opportunity cost derived from the project was proposed by Segui, 2005 and Hernández *et al.*, 2006. While some of these factors identified can be calculated directly, in monetary terms, others like biophysical and social aspects demand the definition of units of measurement.

From the economic viewpoint, it is significant to evaluate the comprehensive influence caused by greywater reuse systems. The influence includes the internal and external impacts such as the social and environmental impacts. According to Bigtan 2008, by including benefits and costs beyond cash flow, economic analysis results may favour reclaimed water projects. This paper focuses on cost benefit analysis of on-site greywater reuse in two buildings- the School of Civil and Environmental Engineering, University of the Witwatersrand, WITS (representative of an educational institution) and a 16 person residential unit at Student Town, Kingsway Campus, University of Johannesburg, UJ (representative of a residential dwelling).

2. Methods

2.1. The Greywater Reuse Pilot System

The greywater reuse system depicted in Figure 1 was implemented at both pilot sites (Section 2.2). Greywater is collected from 12 bathroom hand basins[1] at WITS. At UJ, greywater is collected from 2 showers and 2 baths only[1]. The greywater then passes through a chlorinator[2] which disinfects using chlorine tablets before it passes through two 2mm sieves[3] in series which are housed within a cylindrical pipe[4]. A cistern block[5], which provides colour to the greywater, is inserted into one of the 2mm sieves weekly. The sieved greywater is then stored within a 200 litre greywater tank[6] which houses 2 submersible pumps (each pump is connected to a toilet). When pressed, the bell switch[7], which is mounted on the wall close to the toilet cistern, activates its pump and conveys the sieved greywater into the toilet bowl[8] for flushing. A knob[9], located on the municipal supply into the cistern provides a primary back-up when the greywater system fails. The knob is simply turned to revert to the municipal supply. A tank[10], situated close to the greywater tank, stores municipal potable water at WITS (rainwater at UJ) and provides an additional back-up water supply to the greywater tank when greywater drops below a prescribed level. Several overflow pipes[11, 12, 13] convey excess greywater to the sewer.

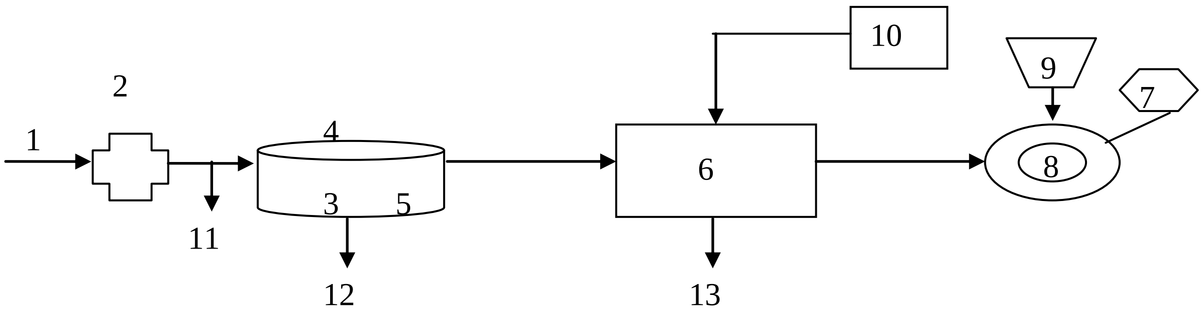

Figure1. *The implemented greywater reuse system for toilet flushing at WITS and UJ*

2.2. The Greywater Reuse Pilot Sites

WITS (Figure 2) houses a pilot system. On a peak day, the building typically houses about 480 staff and students. Although there are 12 toilets in the building, only 2 toilets (1 male & 1 female) flush with greywater.

Unit 51A at UJ (Figure 3) houses the 2nd pilot system. The unit which comprises 2 floors, houses 2 toilets, 1 shower, 1 bathtub and 3 sinks on each floor. 2 toilets (one on each floor) are connected to the greywater system.

Figure2. *The entrance into WITS*

Figure3. *The rear view of Unit 51A, UJ*

2.3. Water Savings from The Greywater Reuse Pilot Sites

The average potable water savings due to greywater reuse in 2 of the 12 toilets at WITS amounts to 137 litres per day. This is due to the fact that the savings was calculated for the months of November and December which fall within the off-peak months on the academic calendar. Hence, the average potable water savings was multiplied by a peak factor of 3 to achieve a safe potable water savings. Using a peak factor of 3, the average potable water savings would amount to 412 litres per day. The maximum potable water savings for UJ due to greywater reuse in 2 of the 4 toilets amounted to 72.69 litres per day. Using a peak factor of 2, the savings was calculated for the months of August and September which fall within the peak period of the academic calendar. The potable water savings from UJ amounts to 145 liter per day. The water saved was calculated with the current price of potable water of Johannesburg Water which is R10.58. The price of water for the next ten years was projected on 10% increase per annum.

2.4. Cost and Benefit Identification

2.4.1. Economical Cost

In general, the economic costs for a greywater system can be classified as follows: (1) design costs and permits fee, (2) purchase and installation costs, (3) operation and maintenance costs. The design costs depend greatly on the suitability of the site and the complexity of the system. If greywater reuse becomes a legal practice, it would be expected that a permit would be necessary to construct an appropriate system and that there would be a fee. The installation costs would include materials and labour. These would be site and system specific. In some cases the owner might prefer to do part of the work, but for some specific components of the system a licensed specialist (plumber and/or electrician) would be required. The operation and maintenance costs include costs of energy needed for treatment and conveyance, cost of labour (maintenance personnel), costs of spare parts, and cost of disinfectants (chlorine). The Energy consumed for the operation of the treatment units and for conveying treated greywater to the toilet is at a cost of approximately R10 per month. This was done with the use of meter connected to the pumps. Tables 1 and 2 summarize the capital and recurrent costs over a 10 year system design life for University for Witwatersrand and University of Johannesburg assuming a 5% annual increase per annual.

Table1. *Capital and recurrent costs for the WITS greywater reuse system over a 10-year design life.*

Cost items	1	2	3	4	5	6	7	8	9	10
Cost of the greywater treatment unit (R)	38 045									
Electricity consumption (R)	36	38	40	42	44	46	48	51	53	56
Chlorine (R)	800	840	882	926	972	1 021	1 072	1 126	1 182	1 241
Cistern blocks (R)	360	378	397	417	438	459	482	507	532	558
Service agreement (R)	0									
Pump replacement (R)					7 787					
Total (R)	39 241	1 256	1 319	1 385	9 241	1 526	1 603	1 683	1 767	1 855

Table2. *Capital and recurrent costs for the UJ greywater reuse system over a 10-year design life*

Cost items	1	2	3	4	5	6	7	8	9	10
Cost of the greywater treatment unit (R)	38 200									
Electricity consumption (R)	36	38	40	42	44	46	48	51	53	56
Chlorine (R)	800	840	882	926	972	1 021	1 072	1 126	1 182	1 241
Cistern blocks (R)	360	378	397	417	438	459	482	507	532	558
Service agreement (R)	7 200									
Pump replacement (R)					7 787					
Cost of the rain water harvesting system (R)	9 300									
Total (R)	55 896	1 256	1 319	1 385	9 241	1 526	1 603	1 683	1 767	1 855

2.4.2. Environmental Cost

For the purposes of this study, Disability Adjusted Life Year (DALY) was taken as a measurement unit for the impact on human health. DALY is an index of health risk, developed by the World Health Organization (WHO) and the World Bank (Zhang, 2002). DALY is a method to measure the disease burden, which considers the impacts of life loss caused by death, healthy life loss caused by deformity after disease, and healthy life years (WHO, 2005). It is the sum of discounted and age-weighted years of life lost. One DALY corresponds to one lost year of healthy life, and the burden of diseases to the gap between current health status and an ideal situation where everyone lives until old age, free of diseases and with no disabilities (WHO, 2007). DALY is used in many studies for measuring the health risk.

The calculation for health impact focuses on health risk related to the diarrhoea disease. Diarrhoea disease is estimated to be the largest contributor to the burden of water-related disease (OECD, 2007). Many papers limit the evaluation to diarrhoea disease risk (OECD, 2007; WHO, 2007; World Bank, 2007) while there are other microbial contaminations included in water pollution. Worldwide, unsafe water and lack of sanitation and hygiene (WSH) is a key risk factor for diarrhoea and other diseases. Diarrhoea diseases is an important cause of morbidity and mortality in low- and middle-income countries, annually resulting in the death of 4.9 out of every 1 000 children aged less than 5 years in these regions (Prüss et al., 2002, Kosek et al., 2003). In South Africa diarrhoea diseases account for 3.1% of total deaths – the eighth largest cause of death nationally. Among children under 5, diarrhoea diseases are the third largest cause of death (11.0% of all deaths), and the third greatest contributor to the burden of disease, constituting 84% of all deaths attributable to unsafe WSH, or about 13 368 deaths and 8.8% of all disability-adjusted life years (DALYs) in this age group (Table 3) (Norman et al., 2000, Bradshaw et al., 2003).

Table3. *Burden of disease attributable to unsafe water, sanitation and hygiene, by disease, South Africa, 2000.*

Disease	ICD- 9 codes included in the assessment	Deaths	YLLs	YLDs	DALYs
Diarrhoea Diseases	001,002,004,006-009	13368	375476	10685	386160
Schistosomiasis	120	20	445	21617	22062
Internal parasites including ascariasis, hookworm	126-129	46	1612	8956	10568
Total attribute burden		13434	377533	41258	418790
YLLs = years of life lost, YLDs =years lived with disability, DAILY's =disability-adjusted life years, ICD-9 = International classification of diseases, 9th edition.					

Adapted from Lewin et al 2007

In the literature, the valuation of health risk is calculated at the national or regional level (Zhang, 2002). Valuing the environmental health impact at the level of small project is a neglected issue. In this paper, we would adopt an indirect valuation method to assess the health impact from the percentage of population affected by the reuse project. Therefore, the health risk was determined by multiplying the DALY number of diarrhoea risk caused by the project and the DALY cost rate.

DALYs number for WITS (approximately 450 students and 40 staffs ≈ 500)

= DALY rate × Population (fraction of South African population of 50 million in mid 2010)

$$= 386160 * \frac{500}{50 * 10^6}$$

=3.86 DALY/year

DALYs number for UJ (approximately 16 legal occupants)

= DALY rate × Population (fraction of South African population of 50 million in mid 2010)

$$386160 * \frac{16}{50 * 10^6}$$

=0.12 DALY/year

According to Pegram et al., (1998), the total cost for treating diarrhoea was estimated to be 3.375 billion Rand / year in 1995. It was assumed with 5 % increase in the price of commodity yearly, the health cost on diarrhoea will amount to 7.4 (R m/yr) in 2011. Therefore:

DALY cost rate

=Total health cost on diarrhoea / DALY amount in South Africa

$$\left(7.4*10^6 \big/ 386160\right)$$

= 19,100 Rand/DALY

So the health impact of the project can be calculated finally as following.

Valuation of health impact for WITS

= DALY's cost rate × DALY's number x Impact factor

= 19,100 x 3.86 x 0.002

= 147 Rand /year

Valuation of health impact for UJ

= DALY's cost rate × DALY's number x Impact factor

= 19,100 x 0.12 x 0.002

= 4.6 Rand /year

2.4.3. Economical Benefit

Economic benefit is the savings in municipal water as a result of greywater reuse. It is calculated based on municipal water price, and the annual average of savings due to greywater reuse. The current price of municipal water is 10.58/m^3 in Johannesburg water in 2010. Observing the yearly increase it is was discovered that the municipal water increase is between 7 to 14% per year. Thus, table 4 presents the economic benefit for WITS and UJ over a 10 year design life. The peak savings of 412 litres per day due to the 2 greywater reuse toilets was adopted in this analysis for WITS while savings of 145 litres was adopted for UJ.

Table4. *Benefits of the UJ and WITS greywater reuse system over a 10-year design life*

	Case Study	**UJ**	**WITS**
Economic benefit - Savings in municipal potable water as a result of greywater reuse	Average savings in potable water per day due to greywater reuse in 2 toilets (litres)	145 L	412 L
	Annual average savings in potable water due to greywater reuse in 2 toilets (litres) (x 330 days for WITS and 200 days for UJ)	29.07 kL	135.95 kL
	Annual potable water savings at R10.58 per KL	R 307.60	R 1 438.37
Environmental benefit – Reduced sewage treatment costs due to reduced return flows	Average savings in sewage per day due to greywater reuse in 2 toilets (litres) (approximately 55% of potable water savings due to greywater use)	79.95 L	226.59 L
	Annual average savings in sewage due to greywater reuse in 2 toilets (litres) (x 330 days for WITS and 200 days for UJ)	15.99 kL	74.77 kL
	Annual sewage savings at R7.00 per KL	R 111.93	R 523.41

2.4.4. Environmental Benefit

The principal environmental benefit of water recycling system is savings from sewage bill. It is expected that money saved from sewage can be calculated from potable water savings, and can be calculated to be approximately 55% of the potable water savings. Therefore the environmental benefit = Average savings in sewage (calculated from potable water savings) × Sewage cost.

2.5. Method of Calculation

2.5.1. Cost-Benefit Comparison

After valuating the full benefits and cost items, the present values of cost and benefits can be evaluated. The following equations represent the valuation process. C_O means economic cost and C_E is environmental cost. B_O denotes the economic benefits and B_E denotes the environmental benefits. According to this research the discount rate for the study is 10%. The evaluation period is assumed to be 10 years. The plant's operation is assumed to be at the same level during the period considered, which means the consumption of energy and chlorine would be the same during the year.

$$C = C_O + C_E \tag{1}$$

$$B = B_O + B_E \tag{2}$$

The comparison between cost and benefit could be presented through the ratio of benefit and cost, RB/C. The result is used as the criterion for economic feasibility. So if RB/C > 1, the project is economic feasibility. If RB/C < 1, that means the project is not economic feasibility.

2.5.2. Net Present Value Calculation

The cost benefit analysis scenarios were compared by calculating the net present values of the net costs and benefits over the analysis period. Net present value is an aggregated value used in cost benefit analyses to measure the resultant financial and economic benefit of a good or a service when all costs and benefits are taken into consideration. NPV calculations first discounts each future cost and benefits value to a present value, using an assumed discount rate, and then aggregates the set of present values into a single number that represents the outcome of a particular scenario. A positive NPV indicates a net benefit and a negative NPV a net loss for a particular scenario (Schuen *et al.*, 2009). Scenarios can also be compared – those with higher NPV values are the more favourable. This can be calculated based on the equation below:

$$NPV = \sum_{t-1}^{T} \frac{C_t}{(1+r)^t} - C_0 \tag{3}$$

Where

t - The time of the cash flow

r - The discount rate (the rate of return that could be earned on an investment in the financial markets with similar risk.)

C_t - the net cash flow (the amount of cash, inflow minus outflow) at time *t*.

C. Payback period

The formula or equation for the calculation of payback period is as follows:

Payback period = Investment required / Net annual cash inflow (4)

3. Results and Discussion

Table 5 and 6 presents Net present value (NPV) for WITS and UJ over a 10 year design period. The results were presented based on the current situation with the implementation of 2 greywater toilets in WITS and UJ. The Economic and Environmental costs were calculated based on capital and recurrent costs for the WITS greywater reuse system over a 10-year design with the assumption of 5% increase annually. While the economic (Potable water saving) and environmental benefits (sewage treatment savings) of the greywater system was calculated based on an annual increase of 10% and 8% per annum for both sites. This assumption was based on data collected from Johannesburg water website on water and sewage bills. The result from WITS over a ten-year period as shown in table 5 indicated that the cost of benefit ratio of the project is 0.36 while the net present value of the resultant income stream over a ten-year period is –R31, 950. From the result, it can be deduced that implementing greywater project for toilet flushing is not economical under a 10-year period but there is evidence of return of investment after 20 years based on the payback period. In addition, the result in table 6 for

UJ shows a cost-benefit ratio of 0.06 and the Net present value of –R59, 760 with the negative NPV over 10 years and negative benefit cost ratio. The payback period was calculated to be 133 years, which is more than the expected life expectancy. It can be deduced that there is no possibility of getting a payback under this current situation. These results also confirm reports in literature that domestic scale greywater reuse system is not economical under current water tariff charges. The greywater reuse system will only becomes viable when there is an increase in price of potable water and cost of treatment unit is subsidized since it constitutes a major part of investment.

Table5. *Benefit/Cost ratios of the WITS greywater reuse system over a 10 year design life*

	Present value	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**	**Year 10**
Cost (R)	48 319	39 241	1 256	1 319	1 385	9 241	1 526	1 603	1 683	1 767	1 855
Health Impact (R)	437	147	154	162	170	179	188	197	207	217	228
Water savings benefit (R)	13 076	1 438	1 582	1 740	1 914	2 106	2 317	2 548	2 803	3 083	3 392
Sewage savings (R)	4 387	523	565	611	659	712	769	831	897	969	1 046
Free Cash Flow (R)	30 856	37 426	737	870	1 019	6 601	1 372	1 579	1 810	2 068	2 354
Interest rate	10%										
Benefit/Cost ratio	**0.36**										
Net Present Value (R)	**-R 31 950**										
Return on Investment	-8%										
Payback period	**20years**										

Table6. *Benefit/Cost ratios of he UJ greywater reuse system over a 10 year design life*

	Present value	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**	**Year 10**
Cost (R)	63 460	55 896	1 256	1 319	1 385	9 241	1 526	1 603	1 683	1 767	1 855
Health Impact (R)	79	5	5	5	5	6	6	6	6	7	7
Water savings benefit (R)	2 796	308	338	372	409	450	495	545	599	659	725
Sewage savings (R)	938	112	121	131	141	152	164	178	192	207	224
Free Cash Flow (R)	59 726	55 485	806	825	844	8 649	878	892	904	913	920
Interest rate	10%	0.1									
Benefit/Cost ratio	**0.06**										
Net Present Value (R)	**-R 59 790**										
Return on Investment	-13%										
Payback period	**133years**										

4. Conclusion

This paper has analyzed the economic feasibility of on-site greywater reuse systems for toilet flushing for a residential and non-residential university building by examining the costs and benefits. From the results above, we have seen that there is the possibility of return on investment under the non-residential reuse which confirms the fact that if the water is reused on a large scale basis, there is potential for return on investment. This also confirms the fact that the economic benefits are very sensitive to building size and to the price of water. It is believed that if on-site greywater reuse practice becomes widespread, the costs of the systems will obviously decrease, making them more appealing to individual consumers to buy and implement. The results also show that personal benefit could be achieved not only from the reduced overall water consumption but also from reduced sewage flows which sometimes may not carry any financial burden. In conclusion, this research has demonstrated that on-site greywater reuse is a feasible solution to decreasing overall urban water demand, not only from an economic profitability, but also from environmental standpoint under typical conditions.

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