Techno-economic analysis of sustainable water management techniques – a case study of residential township in India

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Abstract: Technically efficient and economically viable methods of rooftop rainwater harvesting, greywater recycling and use of low flow devices for integrating in residential townships are identified. An integrated tool is developed for generating designs of identified techniques along with the estimates of capital costs required for installation and the total net present cost. It also calculates potential of water saving. A case study of a residential township in Nagpur, India has been presented. Unit cost and current net value of water using these techniques are calculated. Unit costs of water per cubic meter using rainwater harvesting, low flow devices and greywater recycling are found to be INR 230 (1USD = INR 55), INR 38 and INR 124 respectively. The current net value of water saved using rainwater harvesting; low flow devices and greywater recycling are INR 388,080 INR 162,437 and INR 70,560. Total cost of installation of these three techniques for the case study of residential township is INR 19,813,866, i.e., only 1.14% of the total cost of the project. This study enables prioritisation of practicing rainwater harvesting, use of low flow devices and greywater recycling for conservation of water as well as evaluation and allocation of the percentage of land area required for these techniques.

Keywords: rainwater harvesting; LFDs; sustainable renewable resource management; SRRM; techno-economic; net present cost; greywater recycling; India.

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1 Introduction

Owing to the economic drivers, urbanisation is taking place at a rapid pace. In India, population is expected to stabilise around 1,640 million by the year 2050, when compared with the availability of approximately 500 km^3 /yr at present the water availability around 2050 needs to be almost threefold (Gupta and Deshpande, 2004; Ministry of Home Affairs, 1996). In 1951, the per capita water availability was about 5,177 m^3. This has now reduced to about 1,545 m^3 in 2011 (Water Resources Division, TERI, 2011). The global warming, caused by deforestation and urban economic growth, result in the melting of Himalayan glaciers and reduction of water flow in the glacier-fed rivers (Islam, 2012). By 2030, the major sources of water in India, the Ganges and the Brahmaputra will become an unreliable source of water (see http://www.futuredirections.org.au/). Groundwater sources are also getting depleted at a faster rate due to over extraction by the farmers for agriculture in India. Surface water bodies are becoming susceptible to unregulated industrial discharge resulting in increased eutrophication and algal blooms. Conventional groundwater and surface water sources are becoming increasingly vulnerable to anthropogenic, industrial and natural pollution (Sharma and Gulati, 2015). The World health organisation has estimated that there will be a severe water crisis by 2025 (NEERI, Guidance Manual, 2007).

India is highly vulnerable to the adverse impacts of limited water resources due to a large range of topographic, climatic and demographic conditions (Jain 2012). Moreover, the developing cities in India are up-coming, with large residential townships and are exerting excess pressure on water demand, in turn adversely affecting the environment (Mall et al., 2006, 2007; Bhatt and Mall, 2015). Efforts on war footing are essential for saving every drop of water in residential townships. The major solution of this water scarcity, the grave problem is promoting water use efficiency and water reuse.

Rainwater has been acknowledged to promote potable water savings in different types of buildings and in different countries (Villarreal and Dixon, 2005; Ghisi, 2006; Al-Houri, 2014). It has also been reported by different researchers that the reuse of greywater also promotes potable water savings in buildings (March, 2004; Al-Jayyousi, 2003). There are few reports on the saving of water using a combination of rainwater harvesting, greywater recycling to promote potable water savings (Dixon A, 1999). One of the best means to reduce water demand is the installation of water saving technology. Efficient showerheads, faucets, and toilets can reduce water use in the residential townships (http://www.ext.colostate.edu). The economic feasibility of implementing these techniques is the basic hurdle.

The main objective of this article is to identify technically efficient and economically viable water conservation techniques for integration in residential townships. The goal is also to develop a tool for designing these water conservation techniques useful for estimating the installation costs, calculating the net present cost and the potential of water savings using identified techno-economic water conservation systems. It ultimately aims at economic analysis and prioritisation of water conservation technologies based on unit cost and current net value (CNV).

2 Mathematical models and methods

2.1 A case study

The case study of residential township consisting of seven storied apartment buildings is identified. The residential township is spread out over 8.053 hectors of area. The residential township is located in Nagpur, India at latitude of 21.1438° north and longitude of 79.0926° east. The apartment buildings have 413 numbers of 2 BHK apartments and 112 numbers of 3 BHK apartments. A mandatory open space of 8,163 m^2 and an amenity space of 12,343 m^2 is provided in the township. The total cost of the project is INR 190 crores. The chosen case study area is climatologically a semiarid region upcoming with many residential townships creating water shortages.

2.2 Identification of techno-efficient water conservation technologies

The residential built environment is a major untapped resource that could be exploited for water conservation (Friedler and Hadari, 2006). In residential townships, RWH, greywater recycling and use of low flow devices can play a vital role in conservation of water. Out of total consumed water 75% of water can be recycled using RWH and greywater recycling (Nzewi, 2011). Use of low flow devices can save 43.2% of water compared to conventional fixtures.

2.2.1 Rooftop rainwater harvesting

Rainwater is an alternative water supply while preventing flooding and water scarcity. Rooftop rainwater harvesting can be done either by storing rainwater or by recharging of ground water. RWH using underground storage is recommended for residential townships mainly for landscape purpose. It requires minimal treatment and hence is cost effective.

The rooftop RWH system consists of components of catchment, delivery system and a storage tank. Flat cement roofs are most suitable and clean for residential apartments which form a major part of residential townships (Farreny et al., 2011). The proposed delivery system consists of polyvinyl rainwater pipes, a first flush stand pipe, and Varun filter. Polyvinyl chloride rainwater pipes are easy to install, have long life and are most economical (Texas Water Development Board, 2005). The diameter of pipe selected for draining out rainwater is based on rainfall intensity and roof area (National Building Code of India, 2005). A first flush stand pipe is used to flush out runoff from the first spell of rain. This needs to be done since the first spell of rain carries a relatively large amount of pollutants from the air and catchment surface. Sieve filters like Rainy filter, Popup filter, Aqua filters and Varun filters are commercially available filters in India. Varun filter developed by S. Vishwanath is suitable for domestic purpose constructed on principal of a slow sand filter and can handle 50 mm per hour intensity of rainfall from a 50 mm per square meter. It consists of three layers of sponge and 150 mm thick layer of coarse sand. It is suitable in Indian climatic condition (Center of Science and Environment Web Net). Ready underground PVC storage tanks are available in Indian market, but these tanks show bursting when the ground water level is above the base of the PVC tank, in empty condition. Aboveground ecofriendly bamboo tanks having a 1,500 litre capacity, costs INR 1,000 (Mahajan, 2006). Ferrocement tanks cost INR 2.5/litre (http://www.rainwaterharvesting.org). But these tanks cannot be used below ground and occupy land space. Underground reinforced concrete storage tank is found convenient for residential apartment buildings preventing light penetration, keeping stored water constantly cool, and also saving on space (Texas Water Development Board, 2005). Reinforced cement concrete is the inert material, can be effectively utilised for underground tanks. Size of storage tank is calculated to save rooftop rainwater which will be utilised for landscaping and car washing in a residential township. Rainwater reuse is proposed after simple and easy treatment of chlorination. Chlorination should meet the level of 0.2–0.3 mg/l free chlorine (Helmreich and Horn, 2009).

2.2.2 Greywater recycling

Greywater (GW) is generally defined as low strength polluted wastewater originating from bathtubs, showers, hand washing basins and washing machines, but excluding wastewater from the kitchen and the toilet flushing system. GW contains an easily bio-degradable organic content and a relatively low pathogen content, making it much easier to treat and safer to recycle for water uses that do not need potable water quality, such as toilet flushing which accounts for around 20%–30% of the total household water usage and urban landscaping or floor cleaning which comprises about 34% of the total household water budget (Li et al., 2009; Nolde, 1999). Greywater represents the most profitable source in terms of its reliability, availability and raw water quality (Kujawa-Roeleveld and Zeeman, 2006; Nurulet et al., 2008; Ghunmi et al., 2010). Highly efficient and reliable conveyance, storage and treatment systems are required to avoid health risks and negative aesthetics (i.e., offensive odour and colour) (Kim et al., 2009). If the practice of on-site greywater reuse becomes widespread, the costs of the systems will obviously decrease, making them more appealing to individual consumers. In addition, under typical conditions, on-site greywater reuse is a feasible solution for decreasing overall urban water demand, not only from an environmental standpoint, but also in economic terms (March, 2004).Several GW treatment technologies have been developed since1970 which are classified based on physical unit processes, chemical unit processes, physico-chemical processes and biological unit processes. Treatment of grey water can range from simple coarse filtration to advanced biological treatment (Nolde, 2005). Previous studies have suggested that biological processes should be preferred due to the high levels of organics in the water (Nolde, 1995). Biological greywater treatment technology options for greywater reuse include membrane bioreactor (Jefferson, et al., 2000) rotating biological contactor (Nolde, 1999; Friedler et al., 2005) or constructed wetland (Dalas et al., 2004). The major difference between technologies has been the level of suspended solids and micro organism removal. In comparison, direct physical processes are common at very small scale and have been shown to remove solids, but are less effective for organics removal (Jefferson et al., 2004; Ramon et al., 2004). Grey water treatment systems target suspended solids removal to ensure removal of particles associated coliforms prior to disinfection. Evaluation of various technologies shows that membrane bioreactor, electro-coagulation, rotating biological contactor and submerged membrane bioreactor are high energy required techniques. Concern with carbon footprint precludes the use of high energy requirement technologies (Pidou et al., 2007). Energy consumed using a membrane bioreactor is 1.7 kWh/m^3 (Gander et al., 2000). Energy consumed using rotating biological contactor is 1.2 kWh/m^3 whereas energy required for a submerged membrane bioreactor is 3.6 kWh/m^3 (Kader, 2013). The energy required for electro-coagulation is 0.3 kWh/m^3 (Kuntal et al., 2014). GWT technology developed by National Environmental Engineering Research Institute, Nagpur, India (2007), is found techno-efficient, cost effective and does not require energy for the treatment. Figure 1 shows the scheme of techno-efficient GWT technology suitable for residential townships. Sedimentation tanks and filters are the major components of the treatment scheme. Greywater is continuously collected in sedimentation tank which is allowed to flow to filters for treatment. In addition, to provide constant load to the filters, sedimentation tank facilitates settling of coarse particles (>10 mm size). Up flow-down flow filters are chosen for the treatment. The up flow-down flow filter has four columns containing filter media of gravel, coarse sand, fine sand and charcoal. As the name suggests, raw greywater is put at the bottom of first column having gravel (8–15 mm size) and it is collected at the top of second column containing coarse sand (1–1.4 mm size). Water is again fed to the top of third column having fine sand (0.5–0.8 mm size) and collected at the bottom of fourth column having charcoal. Wetland having the depth of 1.0 m is provided at the rate of 1.0 m^2/535 litre of greywater is provided which removes organic matter and pathogens. A collection sump having a capacity equal to half the capacity of sedimentation tank is provided. The design of these components is based on the criteria presented in Tables 1 and 2. Treated greywater has turbidity removal efficiency of 50% (<200 NTU). Hence microbial removal efficiency of this greywater treatment is also approximately 50%. Higher level of compliance is observed when micro-biological analysis is compared to established guidelines for greywater outlined by the World Health Organization and Government of India. Treated water therefore can be recycled safely for the intended use of a toilet flushing in residential townships, efficiently conserving 30% of total volume of water used in residences.

Figure 1 Scheme of GWT technology

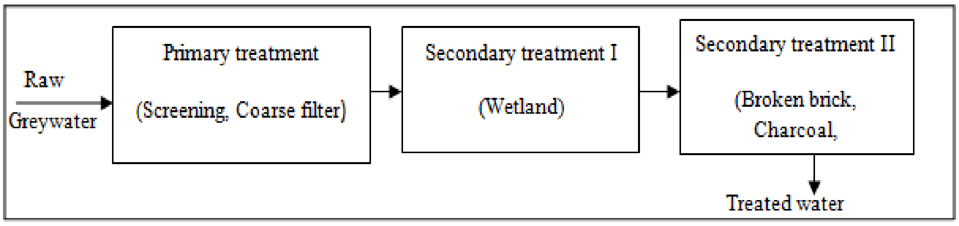

Table 1 Design criteria for sedimentation tank

Parameter	*Range*
Detention time (hours)	1 to 2
Surface loading rate (l/hr/m^2)	500–750
Depth of tank (m)	0.6–1.0
Length to width ratio	3:1 to 4:1

Source: NEERI, Guidance Manual (2007)

Table 2 Design criteria for filters (NEERI, Guidance Manual, 2007)

S. no.	*Parameter*	*Range*
1	Number of compartments	3 to 4
2	Media and size (mm)	Gravel (20–40)
		Gravel (5–20)
		Coarse sand (1–5)
		Fine sand (0.1–1)
3	Hydraulic loading (m^3 /m^2-hr)	0.1–0.3
4	Depth of media (m)	0.4–0.6

Source: NEERI, Guidance Manual (2007)

2.2.3 Use of low flow devices

Low flow fixtures save water that would otherwise be wasted, not only reduce utility bill, but also the amount of available fresh water use. Low flow toilet options available in the market include vacuum or compressed air toilets, macerating toilets, ultra flush toilets (saving water 6.8 lit/flush), dual flush toilets (saving 16 lit/flush). Shower heads, faucets with aerators (saving 50% water) can be installed in residences for conservation of water use (http://www.environment-agency.govt.uk; Wills et al., 2010; Taleb and Sharples, 2011). Dual flush toilet having the maximum water saving capability includes separate water fill tanks in a toilet tank, selectively pivoted to deposit different quantities of water for flushing. M/S of Parryware, Hindware and ESS-ESS Gurgaon, in India, have brought out aerators for faucets and showerheads. These aerators use aeration technology, mixes water droplets with air to cover the desired surface area which helps to deliver a strong spray, saving the consumption of water. The aerators of M/S Parryware, having two dissimilar mesh combination and can save comparatively more water (Living Green in Madera, 2013; Umesh and Nagaraj, 2014). Table 3 shows a comparison of usage of water using conventional fixtures and techno-efficient low flow devices which are available commercially and locally.

Table 3 Comparison of usage of water using conventional fixtures and low flow devices

Particulars	*Avg. daily use of water using conventional fixtures (lpcd)*	*Avg. daily use of water using low flow devices (lpcd)*	*Saving of water (lpcd)*
Drinking	7	7	0
Cooking	5	5	0
Bathing	55	28	27
Washing of clothes	30	20	10
Washing of utensils	26	13	13
Floor cleaning	12	12	0
Flushing of toilets	45	23	22
Total	180	108	72

Source: Rating system for water efficient fixtures – a way to sustainable water management in India Centre for Science and Environment, New Delhi

Proposed techno-economic fixtures for residential townships are the dual flush toilets, shower heads, faucets/taps and pillar cocks with aerators.

2.3 A tool: SRRM

A generalised tool sustainable renewable resource management (SRRM) has been developed in power builder from SAP technology for integrating water conservation techniques for calculation of sizes of components of techno-efficient, economically viable RWH and GW recycling systems for residential townships. Rainfall data, physical dimensions of building, number of users, current rates of the components of RWH, GWR and LFDs is the input of the tool. Computations of the tool uses rates of material and labour obtained from PWD (2012). Current schedule of rates 2012–2013. Rates of chlorination and water are obtained from Water and Sewerage Board, Maharashtra, India for the year 2012. Information obtained from suppliers and consultants of local RWH, greywater treatment systems and low flow devices has been used to complement it. Tariffs of electricity for the residential sector practiced by the local electricity utility are used for calculating the cost of electricity for the year 2012. Installation cost and saving in water using each of these techniques is the output of SRRM tool. A snapshot in Figure 2 shows the input window and computation window for rainwater harvesting system. The tool has a similar input window and computation window for GW recycling and use of LFDs. Calculations of installation cost, operation, maintenance and replacement costs are possible using this tool for each apartment building of a residential township. The summary sheet is generated giving ready values of net present cost for all the three water conservation techniques to be implemented in the residential township. It also evaluates the unit cost of water using these technologies.

Figure 2 Screenshot of input and computed values windows of RWH module of water conservation tool SRRM (see online version for colours)

SrNo	Particulars	Values
1.	Area of terrace (m2)	289.31
2.	Annual Rainfall Intensity (mm)	1000.00
3.	Depth of ground watertable (m)	3.00
4.	Depth underground concrete water tank (m)	2.50
5.	Runoff coefficient	0.80
6.	Dia. of pipe (mm)	100.00
7.	Length of rainwater PVC pipes (m)	51.00
8.	Capacity of a filter to filter water from terrace area (m2)	100.00
9.	Life of RWH system (Yrs)	65.00
10.	Life of strainer (Yrs)	10.00
11.	Life of Overhead Tank (Yrs)	50.00
12.	Life of filter (Yrs)	15.00
13.	Life of pump (Yrs)	10.00

SrNo	Particulars	Computed Value
50.	Cost of electricity for pumping rainwater to overhead tank during lifetime	792780.58
51.	Total Operational cost	1629687.84
52.	Cost of replacing strainers (INR)	54948.85
53.	Cost of replacing filters (INR)	510975.96
54.	Cost of replacing pumps (INR)	457907.09
55.	Cost of replacing overhead tanks (INR)	6510.00
56.	Total replacement cost of overhead tanks during lifetime (INR)	221763.57
57.	Total replacement cost (INR)	2491190.94
58.	Cost of Cleaning of terrace/annum	95.47
59.	Cost of Cleaning of terrace in life time	467202.23
60.	No. of labourers reqd for desludging the tank	1.85
61.	Cost of desludging of tank (INR) per annum	185.00
62.	Cost of desludging of tank during the lifetime (INR)	300737.79
63.	pumps maintenance (5% of Purchase price)per annum	500.00
64.	pumps maintenance during lifetime	246951.20
65.	Total maintenance cost	2029782.43
66.	Life cycle cost (INR)	7741159.55
67.	Rainwater saved in (KL)	30088.24

2.3.1 Cost of water conservation techniques

The total net present cost (C_{NPC}) in equation (1) is used to represent the life cycle cost of each water conservation technique. Life cycle cost includes installation, operation, maintenance and replacement costs as shown in Tables 5 to 7. Cost factor (C_a) is used for obtaining the total net present cost. The total net present cost is calculated for each of the technology using the developed SRRM tool. Operating and maintenance costs obtained using this tool include personnel cost, cost of energy and chemicals.

$$C_{NPC} = C_n / C_a \tag{1}$$

where

C_{NPC} total net present cost

C_n annualised cost

C_e cost of energy

C_a cost factor.

$$C_a = i\,(1+i)^n / (1+i)^n - 1 \tag{2}$$

where

i annual real rate of interest

n life of system.

Table 4 Potential of water saving

Building	*Terrace area* m^2	*No. of families*	*Use of LFDs* m^3*/annum*	*RWH* m^3*/annum*	*GWR* m^3*/annum*
Apartment 1	578.625	56	7,358.4	491	3,924.48
Apartment 2	1,478.0	112	14,716.8	1,256	7,989.12
Apartment 3	1,478.0	112	14,716.8	1,256	7,989.12
Apartment 4	1,743.0	168	22,075.2	1,394	11,773.44
Total	5,277.625	448	58,867.2	4,437	31,676.16

Table 5 Breakup of installation cost of RWH

Item	*Cost (INR)*			
	2 Towers Apartment 1	*4 Towers Apartment 2*	*4 Towers Apartment 3*	*6 Towers Apartment 4*
Strainers	2,400	6,000	6,000	7,200
Filters	30,000	60,000	60,000	90,000
Underground RCC tank	1,511,818	3,861,716	3,861,716	4,554,108
Pumps	20,000	40,000	40,000	60,000
Overhead tanks	13,020	26,040	26,040	39,060
Pipes	13,260	33,800	33,800	50,700
Total installation cost	1,590,498	4,027,556	4,027,556	4,801,068

Table 6 Breakup of installation cost of LFDs

Item	*Cost (INR)*			
	2 Towers Apartment 1	*4 Towers Apartment 2*	*4 Towers Apartment 3*	*6 Towers Apartment 4*
Bibcocks	347,200	694,400	694,400	1,041,600
Pillar cocks	145,040	290,080	290,080	435,120
Showerheads	50,400	100,800	100,800	151,200
Dual flush toilets	392,000	784,000	784,000	1,176,000
Metered wheel taps	176,960	353,920	353,920	530,880
Health faucets	134,400	268,800	268,800	403,200
Total installation cost	1,246,000	2,492,000	2,492,000	3,738,000

The annual real rate of interest of 5% is considered for the year 2012 (see http://www.rbi.org.in/). The life of the GWR system and LFDs is considered as 50 years. The RWH system is assumed to last for 65 years. Unit cost of water saved using RWH, LFDs and greywater recycling is calculated using equation (3).

$$C_u = C_{NPC} / V \quad (3)$$

where

C_u unit cost of water saved

C_{NPC} net present cost

V volume of water saved in life of the system.

3 Results

Table 4 shows the potential of saving in water using water conservation technologies viz. low flow devices, RWH and GWR for apartment buildings of a residential township of Nagpur, India.

Use of LFDs save fresh water of 58,867.2 KL/annum and has maximum potential to save the potable fresh water. GWR saves potable water of 31,676.16 m^3/ annum, which is proposed for toilet flushing after treatment. The water requirement for flushing of toilets, for 448 families of the township at the rate of 225 lit /day/family is 36,792 m^3/ annum. Hence the total available quantity of 31,376.16 m^3 /annum is proposed for recycling. The total terrace area of 5,277.625 m^2 saves 4,437 m^3 of rainwater per annum. Use of this rainwater is proposed for the purpose of landscaping in common areas of residential township apart from landscaping in apartment buildings. The residential township has common landscape area of 10,000 m^2. The water requirement for landscaping is found to be 9,275 m^3 per annum at the rate of 3.5 lit/m^2/day. The installation costs for RWH, use of LFDs and GWR are obtained using SRRM tool. The breakup of the installation costs of water conservation techniques of RWH, GWR and use of LFDs is shown in Tables 5 to 7. Table 5 of the breakup of the installation cost of RWH shows that the cost of underground reinforced concrete storage tank is 95% of the total installation cost required for RWH system. Table 7 of the breakup of the installation cost of GWR reveals that the cost of pipes in greywater recycling is highest 26.18% of the total installation cost of greywater recycling system.

Table 7 Breakup of Installation costs of GWR

Item	*Cost (INR)*			
	2 Towers Apartment 1	*4 Towers Apartment 2*	*4 Towers Apartment 3*	*6 Towers Apartment 4*
Sedimentation tank	99,490	198,980	198,980	298,470
Filter	11,531	23,062	23,062	34,593
Wetland	92,460	184,920	184,920	277,380
Collection tank	49,744	99,488	99,488	149,232
Civil work	95,016	190,032	190,032	282,108
Pipes	140,300	285,100	280,600	420,900
Overhead tanks	11,200	22,400	22,400	33,600
Pumps	36,000	72,000	72,000	108,000
Total installation cost	535,741	1,075,982	1,075,982	1,604,283

Net present costs of water conservation techniques of RWH, GWR and use of LFDs for the case study are obtained using the SRRM tool, shown in Tables 8 to 10. It is seen from Table 8 of the net present cost of RWH that the operation and maintenance cost of the RWH system is negligible, i.e., 0.123% of the total net present cost. The maintenance cost of the pump is the major maintenance cost of the RWH system. The operation cost of using LFDs is nil. The maintenance and replacement cost of using LFDs is 0.875% and 82% of the total net present cost. The operation cost and the maintenance cost for GWR is 0.282% and 2.00% of the total net present cost respectively.

Unit cost of water per cubic meter using RWH, LFDs and GWR is INR 230, INR 38 and INR 124 respectively as shown in Table 11.

Table 8 NPC of RWH (INR)

Parameter	*2 Towers Apartment 1*	*4 Towers Apartment 2*	*4 Towers Apartment 3*	*6 Towers Apartment 4*
Installation cost (INR)	807,742	4,027,556	4,027,556	4,801,068
Operation cost (INR) (chlorination+ electricity)	1,629,688	3,284,956	3,284,956	4,890,982
Maintenance cost (INR) (desludging of tank, cleaning of terrace and pump maintenance at 5% of purchase price)	2,029,782	4,909,335	4,909,335	6,110,846
Replacement cost	2,491,191	5,718,632	5,718,632	7,473,573
Total NPC (INR)	6,958,403	17,940,479	17,940,479	23,276,469

Table 9 NPC cost of LFDs (INR)

Parameter	*2 Towers Apartment 1*	*4 Towers Apartment 2*	*4 Towers Apartment 3*	*6 Towers Apartment 4*
Installation cost (INR) (dual flush toilets, taps, pillar cocks)	1,246,000	2,492,000	2,492,000	3,738,000
Maintenance cost (INR)	1,220,950	2,441,901	2,441,901	3,662,851
Replacement cost (INR)	11,485,075	22,970,150	22,970,150	34,455,224
Total NPC (INR)	13,952,025	27,904,050	27,904,050	41,856,076

Table 10 NPC of GWR (INR)

Parameter	*Apartment 1*	*Apartment 2*	*Apartment 3*	*Apartment 4*
Installation cost (INR)	535,741	1,075,987	1,075,987	1,604,292
Operation cost (INR) (chlorination+ electricity)	2,320,532	4,641,063	4,641,063	6,961,595
Maintenance cost (INR) (civil works, equalisation tank desludging weekly, cleaning of filter media every ten days, cleaning of collection tank every two days, pumps and electromech. work)	11,973,075	23,983,734	23,983,734	35,919,228
Replacement cost (INR)	9,748,208	19,496,416	19,496,416	29,244,624
Total NPC (INR)	24,576,578	49,197,200	49,197,200	73,729,736

Table 11 Summary of unit cost

Sr. no.	*Parameter*	*Unit cost INR/m^3*
1	RWH	230
2	Use of LFDs	38
3	GWR	124

3.1 Current net value

Internationally, CNV approach is used to determine cost of reclaimed water and collected rainwater (Hernandez et al., 2006). Table 12 gives the CNV or cost of treated greywater, collected rainwater and LFDs, worked out on the basis of tap water saved in case of a residential township in Nagpur, India. Water tariffs practiced by the local Municipal Corporation of Nagpur, India, for residential sectors for the year 2011–2012 have been considered. Use of LFDs, GWR and RWH can save water costing INR 388,080, INR 162,437, and INR 70,560.

Table 12 Current net value

Sr. no.	Parameter	Current net value for 365 days
1	Use of LFDs	INR 388,080
2	GWT	INR 162,437
3	RWH	INR 70,560

4 Discussion

Research by Li et al. (2010), mentioned about the usefulness of RWH and GWR using slow sand filtration and pasteurisation for houses in urban areas of Ireland.

Tsai et al. (2011) assessed the impacts on water use achieved by implementing rainwater harvesting and low water demand fixtures and showed how much was the reduction in the water demand. Farreny et al. (2011) presented cost efficiency of only rainwater harvesting strategy in dense Mediterranean neighbourhoods.

Literature giving an economic comparison of all the three mentioned water conservation techniques for multi-storied apartment buildings is not available.

This study implements the water conservation techniques to residential townships having multi-storied apartment buildings, uses locally available components and techniques viz. a technique developed by the National Environmental Engineering Institute, Nagpur, India, for greywater treatment. The selected components and techniques are technically efficient and economically viable. Locally available components and methods of treatment affect the economics of the systems. This research enabled the development of a software tool which facilitates the design, economics, calculations for the amount of potable water saved and carbon footprint due to each integrated water conservation technology. Calculations of life cycle costs of these three techniques have also enabled to identify that GWR is more labour oriented technique and it requires more maintenance.

Zhao and Crosbie (2013) highlighted the need for a system of water charging and metering in Ireland to ensure more careful management of water resources, to promote more sustainable use of water. However, it may so happen that the resource of water gets exhausted and cannot even be purchased. Hence supplementing the existing municipal water supply by selecting the water conservation technique is the best option.

5 Conclusions

This paper analysed the economic feasibility of onsite rainwater harvesting system, greywater reuse system and use of low flow devices in residential townships in the urban sector, since a prerequisite for this practice to become widespread is its economic feasibility to the individual consumer. From the unit cost of water conserved using techniques of RWH, use of LFDs and GWR, it is found that RWH technique of water conservation is the costliest and use of LFDs is the cheapest technique of water conservation. The technique of using LFDs conserves potable water. Though the installation cost is least for GWR, it is labour dependent and tedious because it requires a lot of maintenance.

Ready tool like SRRM makes it possible to obtain optimal designs of water conservation techniques. It estimates the total net present value of the water conservation techniques. Installation costs, operational costs, maintenance costs and the replacement costs are also calculated separately. Total installation cost of all the three water conservation techniques of using LFDs, RWH and GW recycling for the case study of residential township is INR 19,813,866, i.e., only 1.14% of the total cost of the project. Total installation cost of water conservation techniques discussed per tenement works out to be INR 44,227. This cost can be shared by the tenement holders or by the developer. Indian Government can provide subsidy for practicing these water conservation techniques to reduce this burden on the tenement holders. The tool also helps in finding out of percentage of land required for RWH and GWR after treatment. For a case study in Nagpur, India the percentage of land required for these water conservation techniques is 7.0%. It would be essential to reserve the land for water conservation techniques at the planning stage only.

As per availability of funds, developers can prioritise the provision of water conservation techniques. The operation and maintenance cost can be shared by the tenement holders.

Taking into account scarcity of water resources, together with the expected increase in water demand, it would not be acceptable to overlook the water conservation resources. Local authorities will have to make policies to make water conservation mandatory. Practicing these techniques provides additional security to the central water supply system.

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